NO. UMTA-MA-06-0025-77-7

GUIDELINES FOR IMPROVED RAPID TRANSIT TUNNELING SAFETY AND ENVIRONMENTAL IMPACT
Volume I: Safety

A.A. Mathews, Inc.
11900 Parklawn Drive
Rockville MD 20852

JANUARY 1977

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technology Development and Deployment
Office of Rail Technology
Washington DC 20590

Technical Report Documentation Page

1. Report No. UMTA-MA-06-0025-77-7	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle GUIDELINES FOR IMPROVED RAPID TRANSIT TUNNELING SAFETY AND ENVIRONMENTAL IMPACT Volume I - Safety		5. Report Date January 1977
		6. Performing Organization Code
7. Author(s) John D. Bledsoe and Arthur P. Chase		8. Performing Organization Report No. DOT-TSC-UMTA-77-2,I
9. Performing Organization Name and Address A. A. Mathews, Inc.* 11900 Parklawn Drive Rockville MD 20852		10. Work Unit No. (TRAIS) UM704/R7706
		11. Contract or Grant No. DOT-TSC-802-1
12. Sponsoring Agency Name and Address U.S. Department of Transportation Urban Mass Transportation Administration Office of Technology Development and Deployment Office of Rail Technology Washington DC 20590		13. Type of Report and Period Covered Final Report July 1974 to May 1976
		14. Sponsoring Agency Code

15. Supplementary Notes

*All work performed under contract to: U. S. Department of Transportation Transportation Systems Center, Kendall Square, Cambridge MA 02142

16. Abstract

Two of the major objectives of the Urban Mass Transportation Administration (UMTA) Tunneling Program are to lower subway construction costs and reduce construction hazards and damage to the environment.

Volume I - Safety

Examination of construction safety regulations, tunnel construction accident data, and features of underground construction leading to unsafe work show that a systems approach to safety is required. Ten guidelines were drafted to supplement current construction safety regulations (OSHA 29CFR1926). Recommendations for further study and evaluation were made to complete the systems safety approach.

Volume II - Environmental Impact

Investigation of subway construction jobs shows that at least two principles underlie treatment of environmental problems. First, planning and design should consider both short-term and permanent damage to environment, and second, a need for better communication of contractor's planned activities and public concerns so that disruptions can be minimized. Guidelines were developed along these principles and are grouped into the following categories: general, community relations, and specific environmental control techniques.

17. Key Words Safety, Underground Construction Safety, Tunneling Safety, Safety Statistics, Guidelines,	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	122	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This study to develop guidelines for improved rapid transit tunneling safety and environmental impact, described in this two-volume report, was sponsored by the Office of Rail Technology of the Urban Mass Transportation Administration, Office of Technology Development and Deployment. The effort was conducted under contract with the Transportation Systems Center, Contract DOT-TSC-802, for the Urban Rail Supporting Technology Program.

Santo J. Gozzo was contract technical monitor for the Transportation Systems Center. John D. Bledsoe of A. A. Mathews, Inc. was Project Manager responsible for overall coordination and co-author with Arthur P. Chase of Volume I - Safety. Sylvia N. Morrison coordinated the workshop program to survey attitudes of interested agencies and organizations. William C. Shepherd, Sr. served as Project Manager for the initial work on Phase A. Andrew C. Lemer of Alan M. Voorhees and Associates, Inc. was principal investigator and co-author with C. Y. Chang of Volume II - Environmental Impact. Howard Wright and Sally D. Liff conducted significant portions of the research for this volume.

There are significant differences among problems and potential users of guidelines for safety and environmental impact. For this reason, results of this study are presented in two volumes, dealing respectively with safety and environment.

The investigators gratefully acknowledge the assistance and information furnished by staffs of the Bay Area Rapid Transit District, the Washington Metropolitan Area Transit Authority, Metro Insurance Administration for WMATA, the Metropolitan Atlanta Rapid Transit Authority, the National Loss Control Service Corporation, and the many professionals who contributed to the survey phase of the contractual effort.

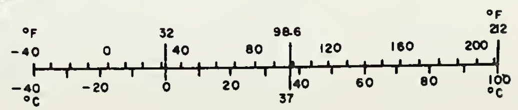
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Meesures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inchas	6.5	square centimeters	cm^2
ft^2	square feat	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilogrems	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	querts	0.95	liters	l
gal	gellons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exect)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius tempereture	°C

Approximate Conversions from Metric Meesures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	squere centimeters	0.18	square inches	in^2
m^2	square meters	1.2	square yerds	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yerds	yd^3
		TEMPERATURE (exect)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS
VOLUME I - SAFETY

APPENDICES

ILLUSTRATIONS

TABLES

1. INTRODUCTION

This is Volume I of a two volume final report under Contract DOT-TSC-802, which reviews safety in underground construction, and the development of guidelines for its improvement. The companion volume addresses the environmental impact of underground construction.

The overall objective of the contract is the generation of recommended guidelines for safety and environmental impact relating to the subway construction process. The contractual effort was divided into two phases, A and B.

1.1 TASK ITEMS

Task items in Phase A were as follows:

Item A-1: (Collect and Review) Current Environmental Impact and Safety Standards and Practices

Item A-2: Problem Assessment

Item A-3: Preliminary Recommendations for Safety and Environmental Impact Guidelines

Item A-4: Prepare Plan for Survey of Attitudes toward Recommended Safety and Environmental Impact Guidelines

Item A-5: Documentation and Information Dissemination

Task items in Phase B were as follows:

Item B-1: Survey of Attitudes towards Recommended Guidelines

Item B-2: Draft Final Safety (and Environmental Impact) Guidelines

Item B-3: Documentation and Information Dissemination

This volume (I) of the final report documents the contractual effort with respect to safety.

1.2 STUDY DIRECTION

The contractual effort was directed towards underground construction applicable to modern rapid transit subway systems in urban areas. There are few differences in safety aspects of underground construction in urban versus rural areas, or for subway construction as compared to that

for other applications. Therefore, this volume on safety is written with the expectation that it will apply to all who are concerned with safety in underground construction.

1.3 DATA ACQUISITION

In fulfilling the requirements of Item A-1, which can be generalized as collection of information, data were received from the following organizations: Bay Area Rapid Transit District (San Francisco), Washington Metropolitan Area Transit Authority (Washington, D. C.), U. S. Department of the Interior, U. S. Bureau of Reclamation, California Department of Water Resources, Metropolitan Water District of Southern California, U. S. Army, Corps of Engineers, Port of New York Authority, New York City Department of Public Works, State of New York Workmen's Compensation Board, California Department of Industrial Relations, California Division of Industrial Safety, California Department of Consumer Affairs, U. S. Mine Enforcement and Safety Administration, and the U. S. Department of Labor.

1.4 DESCRIPTION OF AVAILABLE DATA

Underground construction for the Bay Area Rapid Transit system was completed prior to this contract. Therefore, an extensive file of Contract Documents and inspector's daily reports were available. Several sets of these were obtained (duplicated) and analyzed with the expectation of gaining insight into accident causes. Unfortunately, this approach was not productive because some details were not reported, and also because essential statistical date, e.g., total hours worked, number of accidents, total days lost, were not included in these files. Accident reporting responsibilities had been divided between the Transit District and insurance companies, and the status of records was such that only a few underground construction jobs could be used with confidence.

The U. S. Army Corps of Engineers has merged their historical construction accident data into a single computerized data base so that it is now impossible to study underground construction separately.

The remaining agencies responsible for underground construction listed in the previous subsection provided the historical accident data used in Section 2.

1.5 SUMMARY OF INVESTIGATION

Changes in reporting methods following establishment of the Occupational Safety and Health Administration (OSHA) preclude comparable

analyses of data taken before and after July 1, 1971. Analyses presented in Section 2 show that a few underground construction jobs have been unusually safe, with only 7 accidents reported per million manhours. However, the range extends to 180 accidents per million manhours with an average of 46.

A definite relationship exists between the number of active contracts and the lost time cases per million manhours for subway construction in Washington, D. C. This indicates that skilled labor requirements exceed the availability.

There were not sufficient statistical data to demonstrate a cause and effect relationship for underground construction accidents.

Narrative information from the Bay Area Rapid Transit District and information gained from the construction experience of senior staff members was combined to formulate the description of safety problems in Section 3.

1.5.1 Preliminary Guideline Development

Accident data pertaining to underground construction, as analyzed and presented in Section 2, show that safety regulations have had little effect on the accident rate. A review of hazards in underground construction and features contributing to unsafe work, presented in Section 3, shows that many underlying causes of mishaps involve activities which precede actual construction; e.g., planning, final design, and contractor's selections regarding methods and equipment. Factors found important to safety in underground construction are: planning of the overall project, including preliminary design, division of construction into individual contracts (jobs), scheduling of jobs, selection of contractors, and the owner's participation in the safety program; subsurface investigation and documentation in geotechnical report; final design; and contractor's preparation to cope with encountered conditions.

It is evident that achievement of safety in underground construction requires a systems approach wherein considerations begin with overall project planning and continue through completion of construction. This is the approach used in structuring preliminary guidelines and recommendations in response to Task Item A-3. Brief synopses appear in Section 4.

1.5.2 Guideline and Recommendation Development

Attitudes of owners, contractors, engineers, government agencies, and other interested parties were surveyed in response to Task Item B-1, and described in Section 4. Final guidelines, presented in Section 5, and recommendations, presented in Section 6, were structured following analysis of the survey results.

It is noted that guidelines and recommendations would be used *in conjunction with* 29CFR1926 or other pertinent construction safety regulations to complete the safety system concept.

1.5.3 Additional Considerations

Section 7 presents methods of monitoring and control, estimates of implementation cost, and suggested changes in the interest of underground construction safety.

2. SAFETY STATISTICS

This section discusses the availability and application of safety statistics related to tunnel construction, including sources of information, methods of reporting previously and currently used, and analyses made for this study.

2.1 AVAILABLE ACCIDENT DATA

All available* accident data have been collected from major domestic construction projects involving tunnel construction during the 1960's and 1970's, through 1974. Data on 59 tunnel construction contracts were received and were distributed as follows:

Source	Tunnels
U. S. Bureau of Reclamation	15
California, State Department of Water Resources	5
California, Metropolitan Water District of Southern California	6
New York City, Bureau of Water Supply, West Delaware and Richmond Projects	12
Washington Metropolitan Area Transit Authority	13
Bay Area Rapid Transit District	8
Total	59

Additional data were obtained from the Washington Metropolitan Area Transit Authority (WMATA). These included:

Number of active underground construction jobs for WMATA from 1971 to May, 1975.

Monthly tabulation of manhours worked and lost time cases.

Detailed tabulation of accident data for January to April, 1975.

2.2 INFORMATION REPORTED

Except for the Metropolitan Water District of Southern California, all sources provided data to tabulate the following information:

* The U. S. Corps of Engineers data base does not enable the separation of tunnel accidents from those for all other construction.

Job identification	Number of lost days
Total manhours of exposure	Frequency rate
Number of accidents	Severity rate

The Metropolitan Water District of Southern California did not provide number of days lost or severity, except for work to the end of 1974 for Tonner Tunnel, which was then still under construction.

2.3 REPORTING METHODS

Methods for reporting and compiling accident statistics changed following enactment of the Williams-Steiger Occupational Safety and Health Act of 1970 and the subsequent creation of the Occupational Safety and Health Administration (OSHA). The differences are important to the analysis of historical accident data.

2.3.1 Reporting Prior to Occupational Safety and Health Administration

These methods find their beginning in Bulletin 276 of the U. S. Bureau of Labor Statistics, published in 1920. Following a national conference on Industrial Accident Prevention in 1926, a committee of governmental and private agencies was set up to formulate reporting standards under procedures of the American Standards Association, which in 1966 was reconstituted as the United States of America Standards Institute (ANSI). The work of the committee resulted in the American National Standard Method for Compiling Industrial Injury Rates, Z16.1-1937. Latest revision is ANSI Z16.1-1967 (R1973) (Reference 1). Companion standards are ANSI Z16.2-1962 (R1969), Method of Recording Basic Facts Relating to the Nature and Occurrence of Work Injuries, and ANSI Z16.3-1973, Method of Recording and Measuring the Off-the-Job Disabling Accidental Injury Experience of Employees.

Some important rigorous definitions from ANSI Z16.1-1967 (R1973) are shown in Figure 2-1.

ANSI Z16.1-1967 (R1973) further defines criteria for total days charged for severity calculations. 6,000 days of lost time are charged for death or permanent total disability with tables and charts indicating days to be charged for various types of injuries.

In practice, the provisions of Paragraph 1.4, Regularly Established Job, have not always been followed, which tends to produce a downward bias in both the reported frequency and severity rates.

For practical purposes, frequency and severity can be defined as follows:

1.2.4 *Temporary Total Disability.* The classification for any injury which does not result in death, permanent total, or permanent partial disability, but which does result in one or more days of disability as defined in 1.5.1.

1.2.5 *Disabling Injury (Sometimes Referred to as Lost-Time Injury).* A work injury which results in death, permanent total disability, permanent partial disability, or temporary total disability as defined herein. These are the injuries used in calculating the disabling injury frequency and severity rates.

1.4 Regularly Established Job. One which has not been established especially to accommodate an injured employee, either for therapeutic reasons or to avoid counting the case as a temporary total disability.

1.5.1 *Day of Disability.* A day of disability is any day on which an employee is unable, because of injury, to perform effectively throughout a full shift, the essential functions of a regularly established job which is open and available to him.

1.5.1.1 The day of injury and the day on which the employee was able to return to full-time employment shall not be counted as days of disability; but all intervening calendar days, or calendar days subsequent to the day of injury (including week-ends, holidays, other days off, and other days on which the plant may be shut down), shall be counted as days of disability provided they meet the criteria of the preceding paragraph.

1.7 Exposure (See Section 3). The total number of employee-hours worked by all employees including those in operating, production, maintenance, transportation, clerical, administrative, sales, and other activities.

4. Measures of Injury Experience

4.1 Disabling Injury Frequency Rate. The disabling injury frequency rate is based upon the total number of deaths, permanent total, permanent partial, and temporary total disabilities which occur during the period covered by the rate (see 4.6). The rate relates these injuries to the employee-hours worked during the period and expresses the number of such injuries in terms of a million-hour unit by use of the following formula:

$$\text{disabling injury frequency rate} = \frac{\text{number of disabling injuries} \times 1{,}000{,}000}{\text{employee hours of exposure}}$$

4.2 Disabling Injury Severity Rate. The disabling injury severity rate is based on the total of all scheduled charges for all deaths, permanent total, and permanent partial disabilities, plus the total days of disability from all temporary total injuries which occur during the period covered by the rate. The rate relates these days charged for death and permanent disability and those counted for temporary total disability to the employee hours worked during the period and expresses the loss in terms of a million-hour unit, by use of the following formula:

$$\text{disabling injury severity rate} = \frac{\text{total days charged} \times 1{,}000{,}000}{\text{employee hours of exposure}}$$

FIGURE 2-1. EXCERPTS FROM ANSI Z16.1-1967(R1973)

$$\text{Frequency} = \frac{(\text{No. of lost time cases}) \times 1{,}000{,}000}{\text{Total manhours exposure}}$$

$$\text{Severity} = \frac{(\text{No. of days of time lost}) \times 1{,}000{,}000}{\text{Total manhours exposure}}$$

Severity index has not been widely used in underground construction. Therefore, it is not considered in this study.

Frequency and severity rates calculated as above on the basis of 1,000,000 manhours exposure are useful for study purposes, since a baseline of data extending back for nearly half a century exists. These two statistics are clearly defined and are also familiar to owners, contractors, regulatory agencies, and supervisors and inspectors in the field.

2.3.2 Current Reporting under OSHA

Accident reporting under OSHA started July 1, 1971, following enactment of the Williams-Steiger Occupational Safety and Health Act of 1970. A publication defining measures of injury comparable to those listed in ANSI Z16.1-1967 (R1973) is not yet available. Requirements for recordkeeping by employers are defined in booklets issued by the Department of Labor (References 2 and 3). Definitions of recordable injuries and illnesses as well as lost work days from Reference 3 are shown in Figure 2-2. These definitions became effective January 1, 1975. Slightly different definitions, shown in Reference 2, were effective between July 1, 1971 and December 31, 1974.

Generally, the use of frequency and severity as measures of injury experience have been replaced by incidence. The only definitions of incidence found were in footnotes from Bureau of Labor Statistics Reports, References 4 and 5, and are shown in Figure 2-3. The term incidence is not used consistently, as shown in Figure 2.3. It is generally applied to a rate of recordable injuries or illnesses per 100 full-time workers per year. It should be noted that sometimes it applies to lost workdays rather than recordable injuries or illnesses, and sometimes the base is changed, e.g., to 1,000 full-time workers.

Except for the case of occupational illnesses, incidence definitions have a common baseline of 200,000 manhours. This differs from the baseline defined under ANSI Z16.1-1967 (R1973) by a factor of 5. Two considerations must be kept in mind when comparing accident statistics under the two systems. First, a recordable occupational injury or illness under OSHA is not always equivalent to a disabling injury (sometimes referred to as lost-time injury) under ANSI Z16.1-1967 (R1973). Second, the term incidence refers not only to the number of cases, but also to the number of days lost which is somewhat equivalent to the severity rate under ANSI Z16.1-1967 (R1973).

RECORDABLE OCCUPATIONAL INJURIES AND ILLNESSES are:

1) OCCUPATIONAL DEATHS, regardless of the time between injury and death, or the length of the illness; or

2) OCCUPATIONAL ILLNESSES; or

3) OCCUPATIONAL INJURIES which involve one or more of the following: loss of consciousness, restriction of work or motion, transfer to another job, or medical treatment (other than first aid.)

NOTE: Any case which involves lost workdays must be recorded since it always involves one or more of the criteria for recordability.

OCCUPATIONAL INJURY is any injury such as a cut, fracture, sprain, amputation, etc., which results from a work accident or from an exposure involving a single incident in the work environment.

NOTE: Conditions resulting from animal bites, such as insect or snake bites, or from one-time exposure to chemicals are considered to be injuries.

OCCUPATIONAL ILLNESS of an employee is any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to environmental factors associated with employment. It includes acute and chronic illnesses or diseases which may be caused by inhalation, absorption, ingestion, or direct contact.

The following listing gives the categories of occupational illnesses and disorders that will be utilized for the purpose of classifying recordable illnesses. The identifying codes are those to be used in column 7 of the log. For purposes of information, examples of each category are given. These are typical examples, however, and are not to be considered to be the complete listing of the types of illnesses and disorders that are to be counted under each category.

Column 9A - LOST WORKDAYS–DAYS AWAY FROM WORK

Enter the number of workdays (consecutive or not) on which the employee would have worked but could not because of occupational injury or illness. The number of lost workdays should not include the day of injury or onset of illness or any days on which the employee would not have worked even though able to work.

NOTE: For employees not having a regularly scheduled shift., i.e., certain truck drivers, construction workers, farm labor, casual labor, part-time employees, etc., it may be necessary to estimate the number of lost workdays. Estimates of lost workdays shall be based on prior work history of the employee AND days worked by employees, not ill or injured, working in the department and/or occupation of the ill or injured employee.

Column 9B - LOST WORKDAYS–DAYS OF RESTRICTED WORK ACTIVITY

Enter the number of workdays (consecutive or not) on which because of injury or illness:

1) the employee was assigned to another job on a temporary basis, or
2) the employee worked at a permanent job less than full time, or
3) the employee worked at a permanently assigned job but could not perform all duties normally connected with it.

The number of lost workdays should not include the day of injury or onset of illness or any days on which the employee would not have worked even though able to work.

FIGURE 2-2. EXCERPTS FROM RECORDKEEPING REQUIREMENTS UNDER OSHA

[1] The *mean* incidence rate is calculated as: N/EH X 200,000, where

N = number of injuries and/or illnesses

EH = total hours worked by all employees during calendar 1972

200,000 = base for 100 full-time equivalent workers (working 40 hours per week, 50 weeks per year).

The *median* incidence rate is the middle measure in the distribution—half of the establishments have an incidence rate more than the median rate; half have an incidence rate less than the median rate. The *middle range* (interquartile) is defined by two measures—a fourth of the establishments have a rate less than the first quartile rate and a fourth a rate more than the third quartile rate.

[3] Hereafter, in this section, the incidence rates of occupational illnesses represent the number of illnesses per 1,000 full-time workers, although tables 1 and 4 show the rates per 100 full-time workers. Incidence rates are changed to this base because the rates generated per 200,000 hours of exposure are, in general, quite small.

[6] The incidence rates for lost workdays appearing in this table are the only ones published in this bulletin and were calculated as: LWD/EH X 200,000, where,

LWD = number of lost workdays for injuries and/or illnesses

EH=total hours worked by all employees during calendar 1972

200,000 = base for 100 full-time equivalent workers (working 40 hours per week, 50 weeks per year).

FIGURE 2-3. FOOTNOTES FROM BUREAU OF LABOR STATISTICS REPORTS

2.3.3 Basis Used for This Study

Accident measures used in this study are those defined by ANSI Z16.1-1967 (R1973). This decision was made because most of the available data were compiled under that system, although consistency in the report was an additional consideration. Translation of frequency to incidence of lost time cases by a simple conversion of baseline is not possible.

The few instances where lost time data collected under present OSHA reporting are converted to the million manhour base, are clearly noted.

2.4 STATISTICAL ANALYSIS OF TUNNEL ACCIDENT DATA

Available data for 59 tunnels are tabulated in Table 2-1, showing for each tunnel the location, total manhours, number of accidents, days of lost time (when available), and calculations for frequency and severity.

TABLE 2-1. TABULATION OF TUNNEL CONSTRUCTION ACCIDENT DATA

No.	Location	Total Manhours	Number of Accidents	Days Lost	Frequency 10^6 Base	Severity 10^6 Base
1	Colorado	1,035,257	6	460	5.80	444
2	Washington	927,729	6	191	6.47	206
3	Utah	689,060	5	6,234	7.26	9,047
4	Colorado	627,167	5	6,155	7.97	9,814
5	San Francisco	319,229	3	2,029	9.40	6,356
6	Colorado	692,805	8	6,108	11.55	8,816
7	New York City	1,263,412	16	388	12.66	307
8	Utah	460,023	6	168	13.04	365
9	Washington, D.C.	129,400	2	28	15.46	216
10	Colorado/New Mexico	2,275,732	37	13,834	16.26	6,079
11	San Francisco	366,970	6	144	16.35	392
12	New York City	242,587	4	29	16.49	120
13	California	278,900	5	417	17.93	1,495
14	San Francisco	262,333	5	57	19.06	217
15	New York City	1,020,057	20	1,125	19.61	1,103
16	California	635,166	14	6,212	22.04	9,780
17	San Francisco	90,278	2	68	22.15	753
18	New York City	2,310,455	52	19,861	22.51	8,596
19	New York City	2,205,341	53	1,341	24.03	608
20	New York City	121,333	3	8	24.73	66

TABLE 2-1. (CONTINUED)

No.	Location	Total Manhours	Number of Accidents	Days Lost	Frequency 10^6 Base	Severity 10^6 Base
21	Colorado	527,112	14	264	26.56	501
22	San Francisco	535,130	16	883	29.90	1,650
23	Colorado	2,892,844	87	7,299	30.07	2,523
24	Washington, D.C.	97,620	3	55	30.73	563
25	New Mexico	650,922	21	7,429	32.26	11,413
26	New Mexico	237,627	8	98	33.67	412
27	Washington, D.C.	733,651	26	449	35.44	612
28	New York City	165,623	6	42	36.23	254
29	New Mexico	685,900	25	1,280	36.45	1,866
30	Utah	80,601	3	61	37.22	757
31	Washington, D.C.	455,666	17	200	37.31	439
32	California	3,506,974	144	24,716	41.06	7,048
33	New York City	2,328,073	97	32,978	41.67	14,165
34	Washington, D.C.	1,133,851	48	1,951	42.33	1,721
35	New York City	3,091,387	131	29,338	42.38	9,490
36	Nevada	182,367	8	368	43.87	2,018
37	San Francisco	88,276	4	38	45.31	430
38	San Francisco	715,292	33	479	46.14	670
39	California	932,089	44	923	47.21	990
40	California	2,016,582	98	2,342	48.60	1,161
41	Washington, D.C.	874,390	44	1,133	50.32	1,296
42	California	714,184	38	10,661	53.21	14,928
43	New Mexico	635,738	34	2,278	53.48	3,583
44	New York City	93,475	5	146	53.49	1,562
45	San Francisco	636,624	35	6,565	54.98	10,312
46	California	1,446,808	81	7,278	55.99	5,030
47	Washington, D.C.	906,391	54	1,655	59.58	1,826
48	New York City	2,007,950	120	14,976	59.76	7,458
49	Washington, D.C.	958,298	61	776	63.65	810
50	Washington, D.C.	931,435	63	1,410	67.64	1,514
51	California	117,379	8		68.16	
52	New York City	2,183,547	153	3,372	70.07	1,544
53	Washington, D.C.	339,910	31	340	91.20	1,000
54	Washington, D.C.	569,391	53	1,104	93.08	1,939
55	California	1,238,668	117		94.46	
56	Washington, D.C.	352,996	38	741	107.65	2,099
57	California	821,561	105		127.81	
58	California	1,308,646	179		136.78	
59	California	998,432	180		180.28	

Average frequency and severity rates were obtained by summing the columns in Table 2-1 and then making the necessary calculations to obtain averages shown in the following table:

Average Frequency Calculation from Data Base Summation:		Average Severity Calculation from Data Base Summation:	
Total Manhours	54,166,644	Total Manhours	49,681,958
Accidents	2,490	Days Lost	228,485
Frequency	45.97	Severity	4,599
(Accidents per 10^6 manhours)		(Days lost per 10^6 manhours)	

Scatter diagrams were prepared for the number of accidents per job versus total manhours for job, Figure 2-4, and the days lost for job versus total manhours for job, Figure 2-6. The absissa represents the axis of total safety (no accidents or days lost) whereas the ordinate represents the axis of total disaster. The slope of any straight line passing through the origin represents a rate of frequency or severity.

2.4.1 Achievable Limits for Accident Rates

One application of the statistical analyses discussed above is to obtain an objective answer to the question: "What is a reasonable achievable limit to expect in accident rates?"

Examination of Figure 2-4 and the tabular data shown in Table 2-1 indicates that 7 accidents per million manhours is the lowest observed frequency rate. The five best jobs totaled 25 accidents per 3,598,442 manhours, or a frequency rate of 6.95. This is approximately equivalent to an incidence rate of 1.4 recordable cases per 200,000 manhours.

2.4.2 Distribution of Accident Rates

Cumulative distributions of accident frequency and severity rates are shown in Figures 2-5 and 2-7. These two figures illustrate the distribution of jobs with good and bad safety records. The extremes are summarized in the following table.

	Best 10%	Worst 10%
Frequency Range	0 - 11.6	91.5 - 180.3
Severity Range	0 - 250	9,650 - 14,928

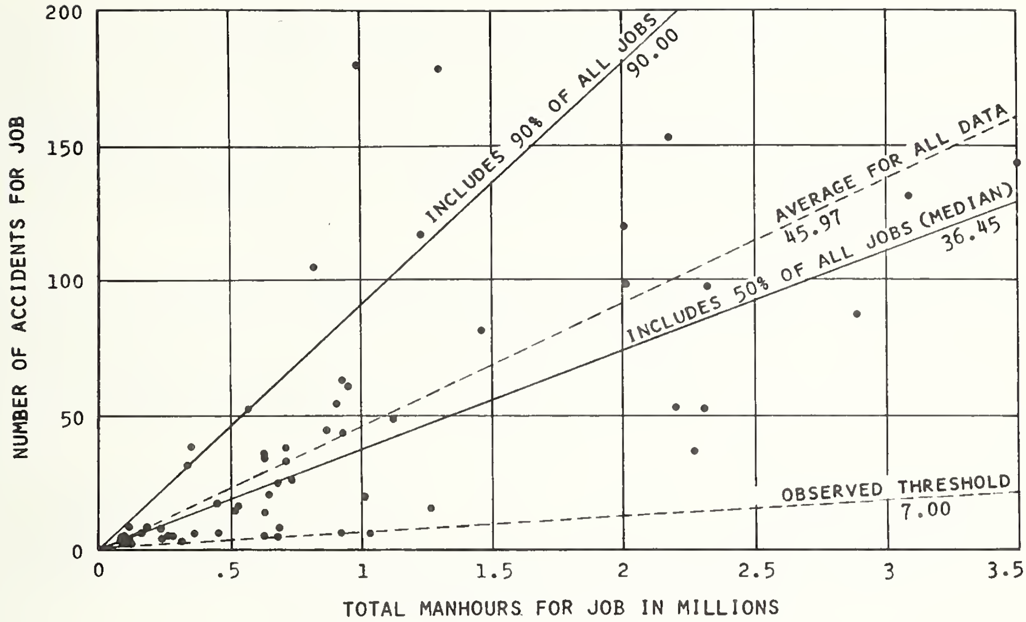


FIGURE 2-4. ACCIDENTS FOR 59 TUNNELS

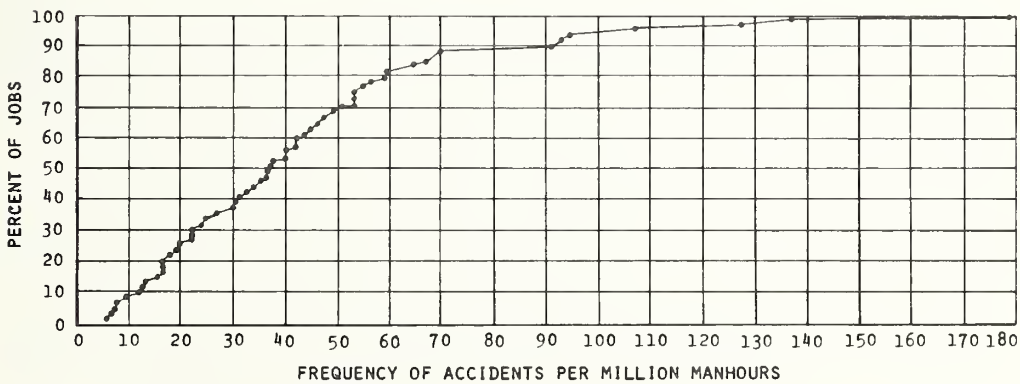


FIGURE 2-5. DISTRIBUTION OF ACCIDENT FREQUENCY RATES

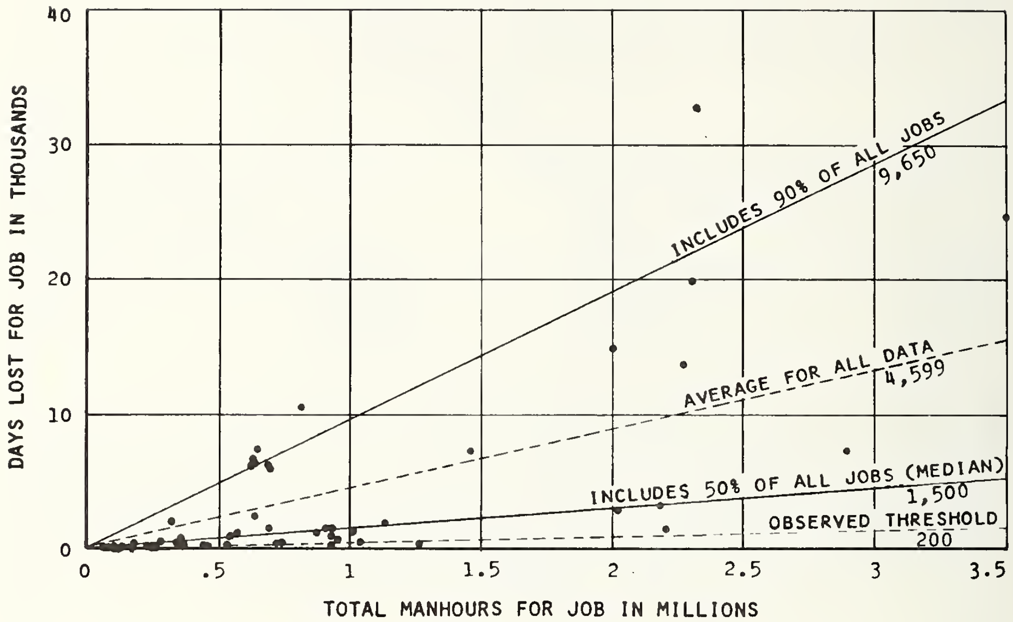


FIGURE 2-6. DAYS LOST FOR 54 TUNNELS

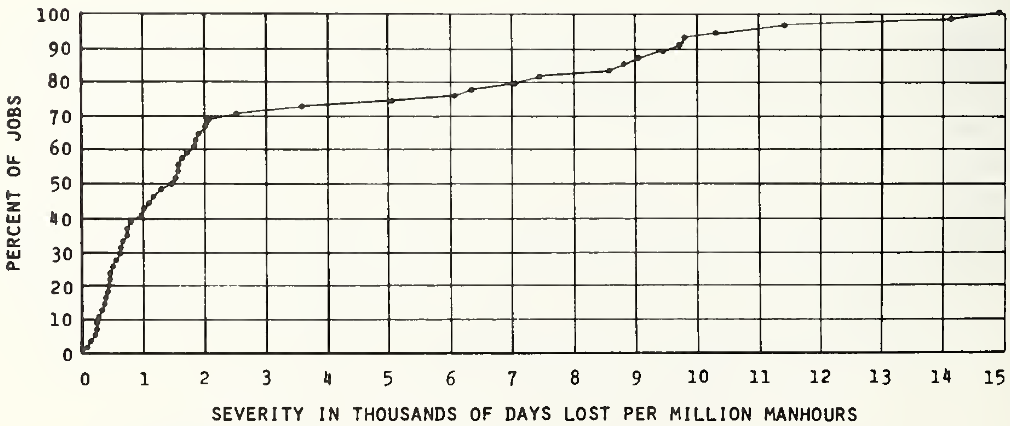


FIGURE 2-7. DISTRIBUTION OF ACCIDENT SEVERITY RATES

The point is that relatively few jobs (and presumably contractors) account for a disproportionate number of lost time injuries and days lost. The data shown here indicate that elimination of 10% of the contractors could cut the range of frequency in half and reduce the severity rate by one third. This is consistent with recent data from WMATA for the period of January through April 1975 which indicate that 41% to 44% of the contractors are responsible for 72% to 76% of total injuries.

It should be noted that severity measures are strongly biased by assessing 6,000 days lost for each fatal accident. This is evident in Figure 2-6 in the cluster of data points between 6,000 and 8,000 days lost, and in Figure 2-7 by the abrupt change in slope of the distribution curve.

2.5 SUBWAY ACCIDENT DATA

Data were collected from the Washington Metropolitan Area Transit Authority (WMATA) for the period of April, 1971 through May, 1975, indicating the number of simultaneous active underground construction jobs, the total number of manhours worked per month by the system, and the number of lost time accidents per month. Frequency and incidence were calculated. These data are shown in Table 2-2.

2.5.1 Effect of Increasing Simultaneous Jobs

A scatter diagram of frequency of lost time cases per month versus the number of active contracts is shown in Figure 2-8. The solid line in Figure 2-8 is the least squares best fit for a straight line for all data. The regression coefficient for all data is 0.62, which is sufficient to establish a definite positive relationship between the number of active contracts and the overall frequency (or incidence) of accidents for WMATA.

Further inspection of Figure 2-8 shows that the data are separated into two distinct groups. An almost random distribution exists from 6 to 22 active contracts. Accident frequency is essentially uncorrelated for this part of the data, as evidenced by a regression coefficient of -0.12.

Beginning at the time when there were 23 active contracts, and continuing through May, 1975 when there were 35 active contracts, the data are clustered at a higher frequency rate, as shown on the right half of Figure 2-8. The regression coefficient for this part of the data is 0.29. Officials concerned with safety statistics at WMATA were not able to identify extraneous effects which might inadvertently bias

TABLE 2-2. MONTHLY CONTRACT AND SAFETY DATA
WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

Month	Number of Active Jobs	Frequency 10^6 Base	Incidence 200K Base	Manhours Worked During Month	Number of Lost Time Cases
1971					
Apr	6	19.84	3.97	302,444	6
May	6	30.75	6.15	227,608	7
Jun	8	35.76	7.15	251,655	9
Jul	8	4.29	0.86	233,015	1
Aug	10	25.19	5.04	277,928	7
Sep	10			missing	
Oct	11	34.51	6.90	260,788	9
Nov	11	33.30	6.66	300,314	10
Dec	11	49.77	9.95	321,448	16
1972					
Jan	11			missing	
Feb	11			missing	
Mar	11			missing	
Apr	12	20.84	4.17	479,794	10
May	13	30.35	6.07	494,288	15
Jun	14	8.74	1.75	343,329	3
Jul	14	25.65	5.13	389,916	10
Aug	15	29.41	5.88	543,977	16
Sep	16	30.36	6.07	592,734	18
Oct	19	28.76	5.75	591,158	17
Nov	21	25.37	5.07	551,736	14
Dec	22	13.90	2.78	647,320	9
1973					
Jan	23	35.11	7.02	598,156	21
Feb	24	38.56	7.71	648,371	25
Mar	26	32.46	6.49	677,726	22
Apr	27	40.52	8.10	765,126	31
May	27	37.70	7.54	822,284	31
Jun	28	39.34	7.87	838,930	33
Jul	28	31.43	6.29	954,471	30
Aug	28	42.81	8.56	1,027,883	44
Sep	28	48.33	9.67	951,835	46
Oct	30	46.57	9.31	1,116,554	52
Nov	30	37.22	7.44	1,101,467	41
Dec	31	32.47	6.49	800,857	26

TABLE 2-2. (CONCLUDED)

Month	Number of Active Jobs	Frequency 10^6 Base	Incidence 200K Base	Manhours Worked During Month	Number of Lost Time Cases
1974					
Jan	31	43.27	8.65	901,411	39
Feb	31	37.32	7.46	884,167	33
Mar	31	39.31	7.86	966,621	38
Apr	31	50.19	10.04	976,256	49
May	31	45.48	9.10	1,209,301	55
Jun	33	43.24	8.65	1,225,585	53
Jul	33	59.10	11.82	1,184,475	70
Aug	32	53.06	10.61	1,187,371	63
Sep	33	56.06	11.21	1,141,546	64
Oct	32	52.18	10.44	1,226,574	64
Nov	33	42.41	8.48	1,343,993	57
Dec	32	35.42	7.08	1,214,163	43
1975					
Jan	34	37.57	7.51	1,197,807	45
Feb	34	46.86	9.37	1,066,924	50
Mar	34	36.35	7.27	1,127,944	41
Apr	34	46.11	9.22	1,257,845	58
May	35	28.75	5.75	869,683	25

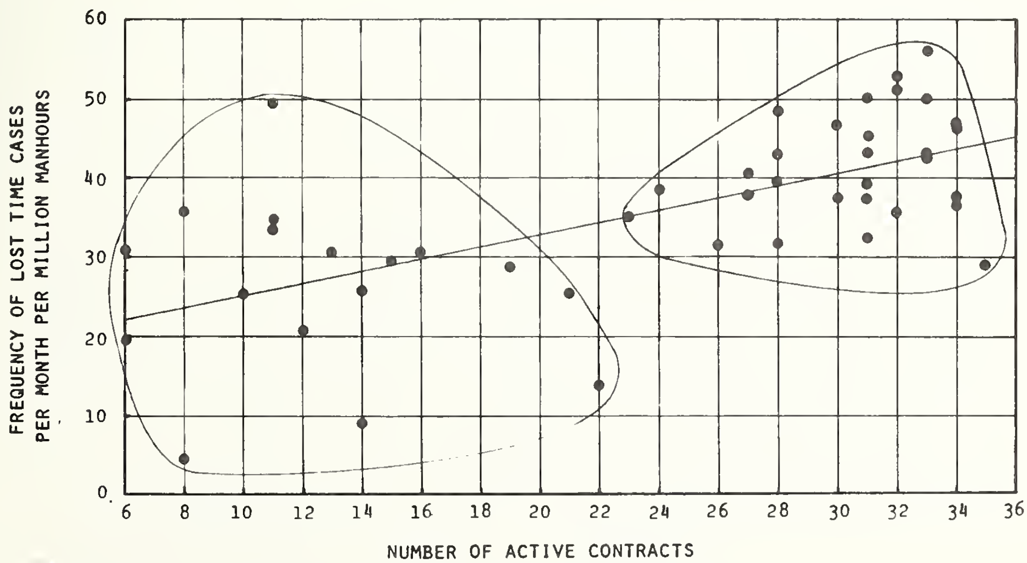


FIGURE 2-8. ACCIDENT FREQUENCY VERSUS NUMBER OF ACTIVE CONTRACTS

the data in the manner shown. Therefore, it can be concluded that a positive relationship does exist between the frequency or incidence of accidents and the number of simultaneous active contracts, and that for WMATA a noticeable change occurred when 23 active contracts were reached.

2.5.2 Accident Characteristics

Data were obtained from WMATA relating to 1470 injuries for the period of January through April, 1975. There was sufficient information to distribute these 1470 injuries according to age group, length of worker experience, trade, and type of accident. The distributions are shown in Figure 2-9. Unfortunately, there is no information available to determine the extent of bias. For example, about 25% of the accidents occurred in the age group of 26 to 30. It is not known whether 25% of the total work force also falls in the same age group. Therefore, while the distributions shown in Figure 2-9 do provide insight into the safety problem, they are not as strong as one would like. The distributions do indicate that laborers and miners in their mid to upper twenties, with from one month to one year of experience, are most susceptible to accidents.

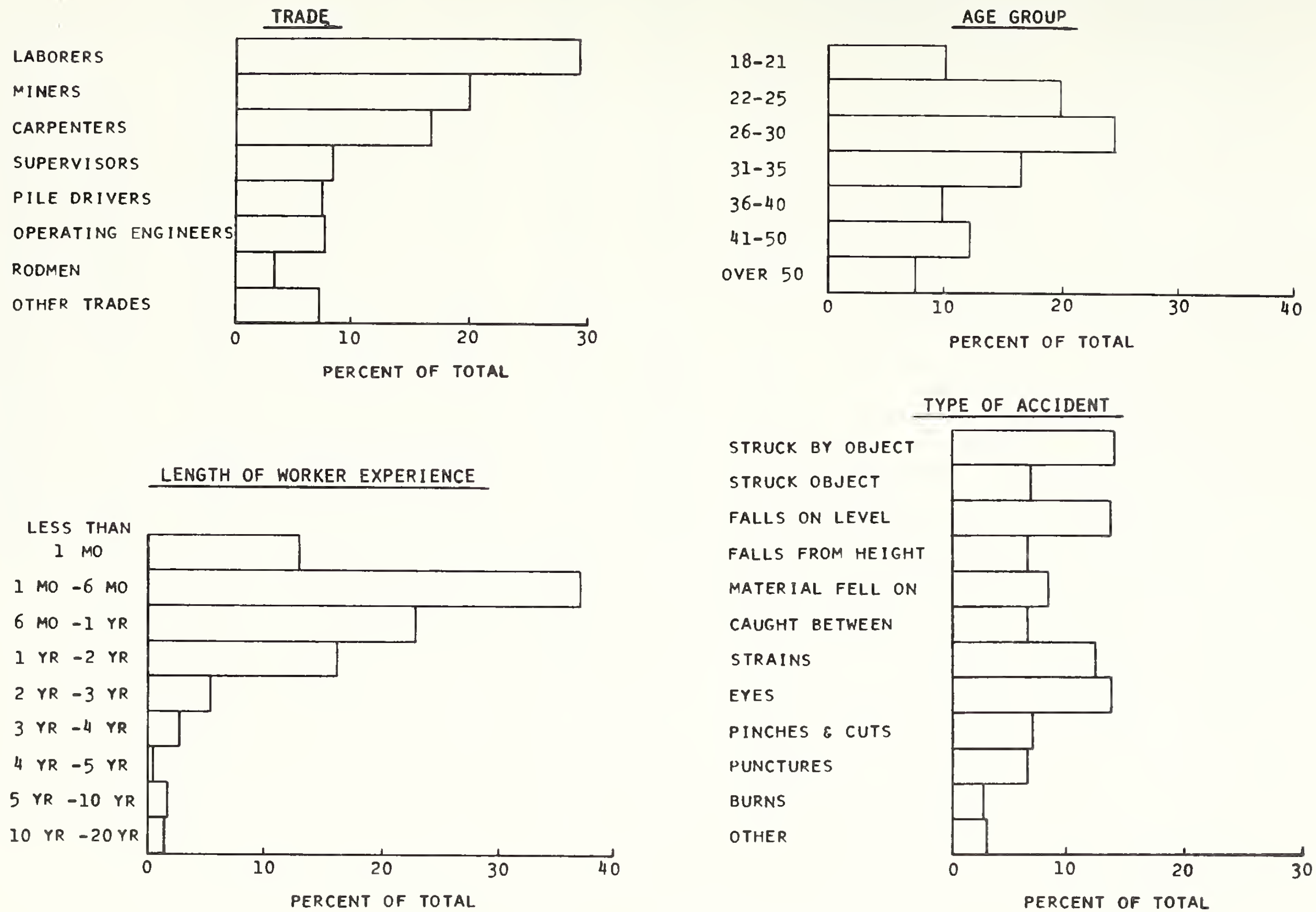


FIGURE 2-9. SUMMARY OF 1470 INJURIES

3. SAFETY PROBLEMS IN UNDERGROUND CONSTRUCTION

Some of the most important insights into safety problems in underground construction are derived from experience. Engineers, supervisors, and workmen with extensive field experience characteristically do not record their observations in sufficient detail to enable statistical analyses. The purpose of this section, therefore, is to document those safety problems which are known to individuals experienced in construction. This section supplements the analyses presented in Section 2.

3.1 HAZARDS IN UNDERGROUND CONSTRUCTION

Most hazards of above-ground construction also exist in tunnel or underground station construction. Many, however, are intensified because of the nature of tunnel construction. Following are some typical hazards of tunnel construction, and conditions which intensify these hazards.

3.1.1 Typical Hazards in Tunnel Construction

a. Restricted vision of equipment operators

b. Riding flat-cars, buckets or skips, and any other equipment unauthorized for personnel transportation

c. Equipment operators not checked out for operating capability and procedures during the different tunnel operations, including speed limitations

d. Inadequate installation and maintenance of equipment safety devices; e.g., brakes, lights, and signal devices

e. Faulty procedures for start-up following inspection or maintenance of equipment protected with lock-out safety devices

f. Misuse of safety devices between coupled cars, resulting in an uncontrolled car in the tunnel

g. Poor installation and maintenance of track and switches, causing derailments and injuries to operators as well as workmen in the tunnel

h. Job-built equipment not properly designed, inspected, and tested

i. More than one man giving signals to the operator causing confusion and increasing accident potential

j. Overloading of equipment, causing equipment failure. In the case of muck conveyances, this can cause rock to fall along the tunnel exposing personnel to hazards.

k. Misuse of power saws, grinders, belt and chain drives, conveyors and similar equipment. Lack of or failure to use safety guards and devices exposes workmen to moving machinery.

l. Barriers around shafts. Inadequate or missing barriers permit materials, supplies, equipment, and personnel to fall into the tunnel below.

m. Barriers above tunnel portals. Inadequate or missing barriers permit falling rock and debris due to freezing, thawing, and precipitation.

n. Falling objects:

1. Rock from conveyors

2. Rock along the tunnel, due to a lack of inspection and re-scaling

3. Equipment, tools, and supplies from overhead platforms and decks due to improper housekeeping, lack of toe boards, and barriers.

o. Footing, including lack of proper hand rails and non-skid surfaces on all walkways, platforms, and decks, especially those exposed to spillage and/or leakage of petroleum products

p. Ladders and landings not installed or improperly maintained

q. Fire, including fumes and exposure resulting from improper methods and devices for fighting specific fire types

r. Chemical burns; e.g., skin and eye irritation resulting from cement additives in concrete, grout, gunite, and shotcrete operations

s. Ram-sets producing flying projectiles resulting from improper operation

t. Compressed air:

1. Inadequate warning before using blow pipes, sand blasters, air-water jets, and blowing air lines

2. Inadequate or non-use of safety devices on air hose connections

3. Use of job-built or used pressure vessels without the proper stamp certifying a test as prescribed for its specific use.

u. Dust from drilling and tunnel boring machine excavation

v. Explosives (See Dupont Blasters Handbook, Appendix B and Chapter 29, General Precautions)

w. Gas, flammable or toxic

x. Inadequate housekeeping

y. Horseplay, causing increased exposure in most hazards mentioned above.

3.1.2 Tunnel Construction Conditions Intensifying Hazards

a. Permanent plant and equipment is not used in tunnels since such equipment is, in most cases, removed upon completion of construction. By contrast, most mine operations can afford the purchase and installation of permanent equipment, which can be used and amortized over a period of many years.

b. The objective of tunnel construction is completed "hole in the ground," whereas in mining, the objective is winning of product on schedule. Tunnel construction is therefore usually conducted on an accelerated schedule as compared to mining.

c. There is rarely an alternate escape route in a tunnel; all personnel, equipment, and waste must enter and leave by the same route.

d. Most work takes place in a relatively small space near the advancing face. This congestion of men and equipment increases the number of hazards and often intensifies the severity of a mishap.

3.2 FEATURES CONTRIBUTING TO UNSAFE WORK

This subsection addresses those features of the underground construction industry which contribute to unsafe work. The term "industry" is used loosely, since the discussion considers all parties involved - owner, designer, insuror, contractor, workman, and regulatory agent. Three items are considered under general discussion; the remainder are divided among five categories used in this study to incorporate all aspects of underground construction safety into a system.

a. Lack of vested interest in safety -- it is unfortunate that at the present time, not one of the parties responsible for or involved in

the construction of tunnels has the cause of safety as its primary vested interest. For example:

The OWNER of an urban transit system is faced with the responsibility of completing construction of the system within a specified time and budget prepared at an early date. His funds are usually derived from the sale of bonds, allocations from jurisdictions, and subsidies from the Federal Government. It is awkward to approach any of these with a request for extension of either time or money. At the same time, the owner is often faced with problems resulting from optimistic cost estimates made during preliminary planning which have become obsolete because of changes in final design and inflation.

The primary concern of the DESIGNER is to produce a design and the necessary contract documents such that permanence of the structure is assured and that the cost of construction will be reasonable. Rarely, if ever, is the designer charged by the owner with making safety of construction a paramount issue in the design.

The CONTRACTOR won the contract because his was the lowest bid. He no doubt spent many hours in finding ways wherein he could economize and thereby arrive at the winning lowest bid. Having won the contract, the contractor now has the responsibility of completing the work and producing a profit.

The LABOR UNION is primarily interested in securing work at the highest possible rate for its membership. Rarely does a labor union have funds to provide pre-work training for its membership.

The INSUROR is a financial institution and is therefore solely interested in increasing its revenue and reducing its obligations. Only to this extent is the insuror interested in construction safety.

REGULATORY AGENCIES are so concerned with the administration of published regulations set forth by their superiors that they often lose sight of their objectives.

The prime interests are essentially those stated above, and, unfortunately, <u>the cause of safety is often neglected</u>.

b. Safety measures considered as extra cost items -- for the most part, the parties actually involved in tunnel construction view safety measures as added cost items. For reasons noted in the subsection immediately above, the contractor is usually dedicated to reducing all costs which are not "pay" items, or are not part of the Work. (Work as used here means the finished construction.)

The owner, for reasons noted above, is equally interested in preventing the cost of construction from rising.

The agencies charged with subsidizing urban transit tunnels find themselves with widespread demands for their limited resources.

It is therefore concluded that, at the present time, safety is viewed as an extra cost item by many of those parties with a direct interest in, and having the resources for, the construction of urban transit tunnels. It should be noted that this conclusion applies equally to all tunnel construction.

c. Division of responsibility or inadequate coordination at construction site -- study of the report of investigation of a recent explosion in modern tunnel construction (Reference 6) indicates that two prime contractors were working independently near opposite ends of a 6 mile tunnel at the time of an explosion. The tunnel had been driven through gassy shale. One contractor was working in the tunnel installing concrete lining. The other was working offshore, preparing to construct an inlet shaft to the tunnel. Either closer coordination between the contractors or control of all work under one authority might have prevented the mishap.

3.2.1 Attitudes and Incentives

Attitude and incentive of both contractor and workman is a complex subject in which factors are often interrelated. Following are items known to be important.

a. Contractor selection criteria -- contractors are presently selected on the following basis:

1. Low bid

2. Balanced bid, or not so unbalanced as to disqualify

3. Sufficient capital or bonding capacity to assure job completion

4. Contractor's experience on similar jobs.

It should be noted that the contractor's safety record on previous jobs is absent from the criteria noted above. Only one case is known to the investigators wherein a contractor's previous safety record resulted in disqualification from bidding. The California Highway Department recently disqualified a contractor who had an unacceptable safety record.

b. Schedule of payments to the contractor -- the contractor is usually faced with a cash flow problem at the beginning of the contract. Even when progress payments are awarded for the mobilization of plant and equipment, they are rarely sufficient to cover actual costs. The

contractor is therefore required to borrow money or invest from his own resources to cover the balance. It is typical for a contract to be about one-third finished before progress payments for completed work are sufficient for the contractor to reach the break-even point. Inflated interest rates intensify this problem. Therefore, the contractor's inclination, if indeed not his only recourse, is to curtail costs at contract initiation, and this includes costs relating to safety.

c. Role of insurance -- system-wide insurance plans help isolate the contractor from his responsibilities for safety. As currently structured in the Washington Metropolitan Transit construction, the owner pays all premiums for both workmen's compensation and general liability insurance, leaving the contractor responsible for deductibles for each claim, and for such items as automobile liability equipment insurance. Similarly, the owner receives any dividends (rebates) which may be returned by the insuror. The contractor shares in neither the monetary penalty for unsafe work nor the benefit for safe work, except in a limited way.

d. Contractor's attitude toward safety statistics -- occasionally, the contractor's staff is interested in enhancing safety statistics to the extent that lost time days are not fully reported. This is usually done by bringing anyone who has suffered an accident to the jobsite and keeping him on the payroll so long as he is able to perform some useful function. Although this provides the workman with more income than he would obtain from workman's compensation, it biases safety statistics. Reaction of workmen toward this practice appears mixed, partly adverse toward safety awards and programs and partly favorable toward the company for aid in maintaining a stable income while recuperating.

e. Workmen's attitude toward safe practices -- it has been established (Reference 7) that workmen will accept voluntary risks more readily than involuntary risks. In other words, workmen will freely expose themselves to danger while, at the same time, they would resist being directed to exposure to the same danger by their foremen. The reasons for such motivation are not clear. It can be explained in part by the attitude of displaying masculinity by the disregard of personal safety. This has historically been a difficult problem to overcome, and the solution will only be accomplished when a way is found to make safe procedures and the use of safety equipment fashionable among construction workmen.

3.2.2 Project Scheduling

As in other human endeavors, the differences between a safe and unsafe tunnel construction job often begin with planning and design of the project. Whenever a major metropolitan area has long delayed the building of an underground mass transit system, and finally decides to "catch up," there is heavy pressure to initiate construction of several segments of the system simultaneously. While this is a viable alternative

from a pure scheduling viewpoint, it has the detrimental effect that there is suddenly an inadequate work force with which to undertake the multiple contracts. Then all of the separate tunneling contracts are prosecuted with poorly trained work forces with the inevitable result that the accident rate is higher than necessary. It was shown in Section 2.5.1 that the accident rate for WMATA changed at the time there were 23 active underground construction contracts.

3.2.3 Geotechnical Program

The origin of numerous tunnel construction mishaps can be traced to encountering ground conditions which were unexpected by the contractor. Causes range from inadequacies in subsurface exploration to the contractor simply failing to review available information.

a. Subsurface exploration -- incomplete knowledge of the ground conditions ahead of the advancing tunnel face have always been a major source of hazard, delay, and increased cost. This problem was given major emphasis by the 1967-68 National Academy of Sciences Rapid Excavation Committee, which stated in its final report (Reference 8): "Geological conditions more than any other factor, determine the degree of difficulty...." Inadequate information regarding subsurface conditions results from the following causes:

1. Insufficient surface geological mapping and exploration.

2. Boreholes spaced too far apart. For example, one tunnel had boreholes spaced up to 5,000 feet apart in an area known for heterogenous geological conditions. It is interesting that the frequency rate for that tunnel was 137 accidents per million manhours, as compared to a threshold of seven for safe tunnel construction.

3. Inadequate specification of borehole program -- for example, if the borehole program does not include the sampling and measurement of gases, then the detection of flammable gases during the execution of the program would only be accidental.

4. Supporting geophysical tests not conducted or improperly conducted -- engineering geophysics is a young technology. Although its worth has not as yet been fully demonstrated, there are definite indications that this advancing technology can contribute to safety through a better definition of subsurface conditions (for example, see Reference 9).

5. Inadequate or incorrect interpretation of available geotechnical data by the engineering geologist or the designer.

b. Hazardous subsurface exploration -- there have been cases wherein the boreholes have of themselves caused hazards to underground construction. These include:

1. Unplugged boreholes penetrating the tunnel alignment -- some results affecting safety have been:

Collapsed tunnel as the advancing face approached the borehole

Running ground or sand entering the tunnel when the face approached the borehole

2. Permanent interconnection of independent aquifers -- the following may occur:

Modification of ground over the tunnel crown, resulting in instability of the tunnel face

Modification or contamination of industrial or urban water supply sources.

c. Inadequate disclosure to contractor -- for example, it has been a common practice to specifically exclude borehole loggings and the like from the contract documents, and dismiss the subject with statements such as: "The Geological Report may be obtained from (address)," or "The core samples may be viewed at (location)." Such statements are usually accompanied by disclaimers such as:

1. The owner's investigation of subsurface conditions at the site of the work was made primarily for design purposes. Drill cores, logs of test borings, geological reports, and similar materials and data obtained in such investigations and made available to the contractor prior to submission of his bid will indicate that character of subsurface conditions only at the points where the borings were taken and shall not, in and of themselves, be considered representations that similar conditions exist throughout the work, or any part thereof, or that other conditions may not be encountered. In no event shall the contractor be relieved of his responsibilities under Section ___, "Examination of the Site" in the bidding requirements and conditions, or under other provisions of the contract.

2. Bidders shall make their own interpretation of the geologic and test boring data and the contractor shall not be relieved of the liability under the contract nor shall the owner or any of his officers be liable for any loss sustained by the contractor as a result of any variance between conditions indicated by or deduced from said geology and test borings and the actual conditions encountered during the progress of the work.

d. Omission of minimum contractor requirements in the case of potentially hazardous geotechnical considerations -- for example, contract documents have been reviewed for the construction of tunnels in potentially gassy conditions for which there was no item in the specifications

relating to the contractor's operations in such gassy conditions, or if present, only the most general statement such as, "The Contractor shall take steps to dilute and render harmless any toxic or flammable gases."

e. Failure of the contractor to adequately consider all available geotechnical information -- for example, there are occasions when, in the examination of a contractor's files in a subsequent claims dispute, it appeared that reports of geological conditions had not been adequately studied.

f. Consequences of inadequate subsurface exploration or failure to consider the available subsurface data include:

1. Inadequate provision in final design for ground support and subsurface hazards

2. Selection, mobilization, and installation of tools, plant, and equipment which may prove unsuitable to cope with ground conditions actually encountered

3. Sudden encountering of adverse conditions; i.e., excessive water, gas, or running ground.

3.2.4 Final Design

The product of the final design is a set of contract documents; i.e., drawings and specifications which define the subsequent construction. Except for unusual situations, the final design must not restrict the contractor's choice of methods, otherwise the owner or designer is faced with accepting responsibilities normally relegated to the contractor, usually at increased cost. On the other hand, the designer should specify certain minimums to the contractor. These include:

a. Minimum pillar width and initial support between twin parallel tunnels for both drill and blast and tunnel boring machine (TBM) construction -- there have been examples when the pillar failed either due to thrust pad pressure exerted by the TBM, or to excavation of the second tunnel prior to placing final lining in the first.

b. Minimum overburden and support for adjacent structures -- one of the most common construction mishaps in subway tunnels is subsidence or even collapse of ground above the tunnel. Results have ranged from minor cracks to major damage in adjacent structures. The designer should establish minimum requirements for items such as allowable subsidence, protection of adjacent structures, and dewatering.

c. Natural hazards -- the two most important natural hazards to underground construction are heavy concentrations of flammable or toxic

gas and large inflows of water. As stated above, planners of subsurface exploration programs have responsibility for searching for these hazards. Having been found, it becomes the designer's responsibility to incorporate sufficient provisions into the contract documents so the contractor will have no excuse for being unaware of potential danger. This can be accomplished by a combination of:

1. Adequate discussion in a Geotechnical Report

2. Specification Items addressing the contractor's minimum requirements to cope with potential hazards -- it has been stated that definition of the problem is half the solution. Formally alerting the contractor to danger can go far in preventing a disaster.

3.2.5 <u>Qualification and Training</u>

With few exceptions, there is no program or legal requirement for the training and certification of individuals or organizations participating in tunnel construction beyond the normal contractor's license required in most states, registration of professional engineers, and certification of blasters. This subsection reviews deficiencies in qualifications and training programs contributing to safety problems and corrective programs being undertaken in California.

a. Pre-job indoctrination -- it is not a common practice for contractors to provide pre-work indoctrination. Consequently, inexperienced workmen gain their first knowledge of underground work and its problems by exposure. It is significant, as shown in Figure 2-9, that 50% of a sample of accidents occurred during the first 6 months on the job, despite a lower accident rate for the first month, probably stemming from apprehension over new working conditions.

It is also not a common practice to provide indoctrination when the nature of the work changes; e.g., when excavation is finished and the next task is to place tunnel lining concrete.

b. Contractor's qualification -- once a contractor has secured his general contractor's license, if required in his state, there is usually nothing to preclude his receiving an award for tunnel construction, even though neither his firm nor any of his key supervisory personnel have any experience in underground construction of any kind. There have been only a few cases when contractor was disqualified by the owner and not given an award. Such action is usually difficult for the owner to defend, and is therefore taken only when the contractor is obviously unqualified. It is rarely taken when the contractor's qualification is marginal.

c. Individual qualification -- most states have individual requirements for blasters and explosive handlers, although not all require

certification. California's recently instituted requirements are discussed in the next subsection. With these exceptions, no requirements now exist for the selection and assignment of supervisors, inspectors, or workmen for underground construction.

d. California certification requirements -- the California Department of Industrial Relations originally published Tunnel Safety Orders in 1945. Following enactment of the Tom Carrell Memorial Tunnel and Mine Safety Act of 1972 (Reference 10, pp. 706.16-707), they were revised as currently published in Reference 10. The act requires licensing of blasters and certification of gas testers and safety representatives. Requirements for obtaining a California Blaster's License are included in Reference 10.

In addition, the California Department of Consumer Affairs, Board of Registration for Professional Engineers, has recently established registration in an engineering specialty identified as "Safety Engineer."

e. Training facility -- no training facility exists for underground construction personnel. The Mine Enforcement and Safety Administration is establishing a Safety Academy for training mine inspectors, and other personnel.

3.2.6 Standards for Tools, Plant, Equipment and Methods

There are, at the present time, few prescribed standards governing the use of tools, plant, and equipment in underground construction. The exceptions are those which fall under industrial health and safety regulations; e.g., hoisting equipment and the use of hard hats. Consequently, contractors, superintendents, and foremen are left to their own devices regarding the tools, plant and equipment used in constructing tunnels. This situation results in a wide range of equipment quality found in use, with instances wherein equipment is modified in the field without engineering supervision or inspection of work. Areas where deficiency is found are as follows:

a. Design

  1. Tools

  2. Plant and Equipment

  3. Personal Protective Equipment

b. Fabrication

c. Test and Acceptance

d. Installation (including field modification)

3.2.7 Compressed Air Regulations

Evaluation of compressed air regulations illustrates a point where safety rules have become so stringent that they are self-defeating. Quite often the use of compressed air in driving a tunnel represents the safest method of performing the work. When unnecessarily stringent regulations make the use of compressed air more expensive, but not necessarily safer, then the rules themselves are at fault. Two aspects of compressed air regulations are considered, medical locks and hours of work.

a. Medical locks -- rules requiring medical locks at the jobsite have changed over the years according to the following table:

Jurisdiction	Rule	Date	When Maximum Air Pressure
New York	1160	May 1, 1922	Exceeds 17 psig.
New York	22-20.2	Oct. 15, 1960	Exceeds 0 psig.
New York	22.23	July 1, 1965	Exceeds 0 psig.
New York	22.26	Jan. 16, 1967	Exceeds 0 psig.
Washington	18.020	Feb. 1, 1963	Exceeds 13 psig.
California	1280(b)	July 3, 1966	Is 14 psig. or above
Washington, DC	9.2.4	May, 1969	Exceeds 10 psig.

Current Federal regulations, OSHA 1926.803(9) (Reference 11) provide as follows:

> "A medical lock shall be established and maintained in immediate working order whenever air pressure in the working chamber is increased above the normal atmosphere."

Discussions with physicians involved in compressed air physiological research indicate that a medical lock must be available for use within the local (metropolitan) area whenever compressed air work is in progress, but that it should not be required at the jobsite unless the working pressure exceeds 12 psig.

b. Hours of work -- hours of work under compressed air have been reduced over the years; e.g., Industrial Code Rule 22 of the State of New York provides (Rule 22.9) as follows:

22.9 Maximum working time within each 24 hours. The maximum number of hours that any person shall work in compressed air at various pressures within a single 24-hour period shall be as set forth in the following table.

WORKING TIME WITHIN EACH TWENTY-FOUR HOURS

PRESSURE		HOURS
Column 1	Column 2	Column 3
Minimum number of pounds	Maximum number of pounds	Maximum total working time
Normal	to 22	6
over 22	" 30	4
" 30	" 35	3
" 35	" 40	2
" 40	" 45	1½
" 45	" 50	1

Requirements shown above are more rigid than stated in OSHA, Appendix A to subpart paragraph 1926.803 (Reference 11). OSHA Appendix A specifies decompression time and schedule as a function of both working pressure and working period. Working periods up to and exceeding 8 hours are accommodated.

Rules which restrict the total of working period plus decompression time below an approximate normal eight-hour shift increase cost but no longer contribute to safety.

3.2.8 Safety Statistics

It was stated in Section 2 that existing safety statistics are inadequate to provide detailed evaluation of safety problems. This is due not only to failure to collect the detailed information for each mishap, but also to absence of a center to separately archive and analyze such data on underground construction. At present, all construction safety data are grouped together, thereby making it impractical to analyze underground construction safety problems separately. In addition, the quality of analysis and reporting of construction accidents has been such that Engineering News Record recently published a critical editorial of the subject (Reference 12).

3.2.9 Patents

Patents are sought because the inventor expects financial reward for his ingenuity. Since patent awards have become both expensive and time consuming, the prudent inventor does not bother unless he foresees a potential market for his invention. Methods for accomplishing a task economically rank high in marketability; safety ranks low.

4. DEVELOPMENT OF GUIDELINES AND RECOMMENDATIONS

This section discusses the rationale for development of guidelines and recommendations presented in Sections 5 and 6, including the relationship between existing safety regulations and the guidelines developed in this study.

4.1 STATUS OF SAFETY REGULATIONS

As noted in Section 2.3.1, Federal safety regulations can be traced back more than 50 years to Bulletin 276 of the U. S. Bureau of Labor Statistics. Following is a summary of recent and existing regulations.

4.1.1 Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA) was established under the Department of Labor as a result of the Williams-Steiger Occupational Safety and Health Act of 1970. OSHA safety regulations covering safety are published as 29CFR1926, with the latest printing and update appearing in the Federal Register, Vol. 30, No. 122, Monday, June 24, 1974. Part 1926 applies to construction, and Subpart S, 1926.8, applies to tunnels, shafts, caissons, cofferdams, and compressed air. (This was formerly published as part 1518.)

The OSHA regulations are detailed and comprehensive. The primary criticism is that the language, like many Federal publications, is difficult to understand.

4.1.2 Other Federal Agencies

The U. S. Bureau of Mines has published Tunneling: Recommended Safety Rules, as Bulletin 644, dated 1968, which is a revision of an older Bulletin 439.

The Mining Enforcement and Safety Administration (MESA), formerly part of the Bureau of Mines, has published Underground Mine Standards, as 30 CFR, Chapter 1, Part 57.

The U. S. Bureau of Reclamation has published Safety and Health Regulations for Construction, Revised Reprint dated March, 1973. Part I is a reprint of the older Department of Labor Part 1518. Part II is the Bureau of Reclamation Supplement.

The U. S. Army, Corps of Engineers, has published General Safety Requirements, EM 385-1-1, March 1, 1967, and Change 1, March 27, 1972.

4.1.3 State Regulations

Many of the 50 states have safety regulations applying to construction, and some have sections applying to tunneling. Many of these state regulations are general and lack the detail found in 29CFR1926. There are, however, some noteworthy exceptions.

Washington State has a well-developed compressed air regulation, and has developed decompression schedules which have found extensive applications elsewhere. Likewise, New York State has developed detailed compressed air regulations for use in tunnels and caissons.

Perhaps the most comprehensive of the state regulations are the California Tunnel Safety Orders, reprinted from California Administration Code, Title 8, Industrial Relations, Subchapter 20, Register 73, No. 34-8-25-73. This regulation offers the most comprehensive rules for control of toxic and flammable gases that the investigators found.

4.1.4 Transit System Safety Manuals

Those transit systems which have recently or are currently undertaking major construction have developed and published construction safety manuals. These include the Bay Area Rapid Transit District (BARTD), the Washington Metropolitan Area Transit Authority (WMATA), the Metropolitan Atlanta Rapid Transit Authority (MARTA), and the Mass Transit Administration, Baltimore (MTA). Most BARTD construction was completed before OSHA 29CFR1926 became effective. Use of the WMATA safety manual was discontinued after OSHA 29CFR1926 became effective.

4.1.5 Limitations of Construction Safety Regulations

Regulations such as 29CFR1926 are established and enforced by regulatory agencies, in this case OSHA. Regulatory agencies are empowered to act only within their jurisdiction. Consequently, existing safety regulations, with few exceptions, apply only to the construction process.

4.2 SYSTEMS APPROACH TO SAFETY

Both the National Aeronautics and Space Administration (NASA) and the Nuclear Regulatory Commission (NRC) utilize the systems approach to achieve unusually high safety performance. NASA's system safety approach is detailed in Reference 24. NRC's safety analysis requirements for nuclear power plants are specified in Reference 25.

The technical principles for applying system safety as identified in a NASA Technology Transfer study (Reference 7) are as follows:

"1. Apply it in every phase of the operation - throughout the life cycle of the product being produced or service rendered

2. Employ some form of hazard analysis in each phase of operation for the purpose of identifying hazards and doing something about them before accidents occur

3. Ensure that all possible lessons are learned from accidents that have already occurred so that these lessons can be used to prevent similar accidents

4. Establish a safety data system that will allow important safety information to be transmitted to, and understood by, management and supervisory personnel who are responsible for making operational tradeoff decisions

5. Clearly establish what the safety requirements are as reflected by:

   - Government regulations and standards (Federal, State, and local)
   - Public protection requirements
   - Insurance carrier requirements
   - Employee protection requirements."

4.2.1 Areas Not Covered by Safety Regulations

Limitations of construction safety regulations are noted above. Hazards in tunnel construction and features contributing to unsafe work were enumerated in Section 3. In general terms, many safety problems have their origins in activities which either precede the actual construction, or which are only indirectly involved in construction.

Some specific areas not covered by safety regulations are:

a. Definition of a safety program for both owner and contractor

b. Selection of contractor

c. Insurance programs for construction of complex multi-contract systems

d. Scheduling of individual construction jobs in a large multi-contract system

e. Specification of underground exploration prior to final design and construction

f. Criteria to be considered in final design and preparation of contract documents

g. Anticipation of and preparation for encountering natural hazards

h. Training and indoctrination of the work force.

In addition, there are factors such as safety standards for equipment and work under compressed air, for which existing regulations should be extended or modified.

4.2.2 Systems Approach to Construction Safety

Adequate construction safety regulations have been in effect for a long time, with no noticeable trend toward safer tunnel construction. It is therefore obvious that new elements must be introduced into the overall safety program for the situation to improve. A systems approach needs to be adopted for safety in underground construction.

4.3 ROLE OF GUIDELINES AND RECOMMENDATIONS

Since existing regulations adequately cover the actual construction process, emphasis of guidelines and recommendations developed in this study is toward those parts of the system beyond the jurisdiction of OSHA and therefore not covered by construction safety regulations. The combination of safety regulations, guidelines, and recommendations constitutes a systems safety approach to tunnel construction.

4.3.1 Restrictions on Guidelines

Guidelines include only those items which could be implemented by a Transit Property (owner), an engineering consultant, or a contractor at the present time.

It should also be noted that most of these guidelines apply generally to all underground construction projects.

4.3.2 Purpose of Recommendations

Recommendations include those items needed to complete the systems approach to tunnel construction safety, but which are not ready for current implementation. For example, some of the recommendations require further research and development or legislative action prior to implementation.

4.4 PRELIMINARY GUIDELINES AND RECOMMENDATIONS

Preliminary guidelines and preliminary recommendations were prepared during the Phase A contractual effort, specifically in accordance with

Task Item A-3, Preliminary Recommendations for Safety and Environmental Impact Guidelines.

4.4.1 Preliminary Guidelines

Preliminary Guideline titles and brief statements follow. Detailed statements are omitted.

No. 1 - Contractor Selection - Consideration of Safety Record
Selection of contractor and award of contract shall be based not only upon lowest bid, but also upon establishment of minimum historical safety record by the contractor.

No. 2 - Mobilization Payments
Mobilization payments to contractors shall be sufficient to enable the procurement of tools, plant, and equipment of the caliber needed to ensure safe construction.

No. 3 - Insurance Programs
Insurance programs should be structured so that contractors with favorable safety performances will be rewarded accordingly.

No. 4 - Owner's Safety Recognition
Each owner shall establish a program to periodically recognize those organizations and individuals who have made outstanding contributions to underground construction safety.

No. 5 - Contractor's Safety Incentive Program
Each contractor engaged in underground construction shall establish a Safety Incentive Program.

No. 6 - Scheduling of Jobs
The scheduling of the individual construction contracts in a system shall not cause the projected pool of available workmen to be exhausted.

No. 7 - Geotechnical Program
A geotechnical program relating to safety shall be conducted for each underground construction project.

No. 8 - Final Design Considerations
Final design considerations relating to safety shall be established for each underground construction job.

No. 9 - Natural Hazard Identification
The contract documents shall identify and define potential natural hazards as well as specify minimum requirements for conduct of work in presence of anticipated hazards.

No. 10 - Contractor's Safety Office and Program
Each contractor engaged in underground construction shall establish a safety office, independent of the operations of any construction project, reporting directly to the management of the firm.

No. 11 - Indoctrination of Workmen
Before being assigned underground, all workmen shall receive indoctrination in the nature of underground work and to the details of the job and their particular assignment.

4.4.2 Preliminary Recommendations

Preliminary recommendation titles and brief statements follow. Detailed statements are omitted.

No. 1 - Contractor's License for Underground Construction
Procedures should be established for the qualification, examination and licensing for contractors specializing in underground construction.

No. 2 - Licensing for Individuals
Programs should be established for the qualification, examination, and licensing of supervisors, inspectors, and selected workmen specializing in underground construction.

No. 3 - Safety Academy
An academy should be established at the Federal level for the training of specialists in underground construction safety.

No. 4 - Safety Standards for Equipment
Minimum safety standards should be established governing the design, fabrication, installation, test, acceptance, and field modification of all tools, plant, and equipment used in underground construction.

No. 5 - Alternative Designs for Equipment
Alternative designs for safety features of tools, plant, and equipment to be used in underground construction should be developed and published so as to be in the public domain.

No. 6 - Compressed Air Regulations
Compressed air regulations governing hours of work, medical lock, attendants, physician availability, and decompression schedules should be re-evaluated.

No. 7 - Reward for Safety Patents
A program should be established such that inventors could expect adequate compensation for patents awarded for safety features or devices.

No. 8 - Collection of Safety Data

Data concerning each underground construction mishap should be compiled and forwarded to a central collection and analysis agency.

No. 9 - Safety Analysis Center

A center should be established whose purpose is the archiving and analysis of data respecting underground construction mishaps.

No. 10 - Contractor Safety Ratings

Safety performance ratings should be developed for each contractor engaged in underground construction and after hearing evidence in support of modification, should be made a matter of public record.

4.5 SURVEY OF ATTITUDES

A survey was conducted as part of the contractual effort, in fulfillment of the requirements of Item B-1 of the Statement of Work, to determine the attitudes of industry, transit system owners, and community representatives regarding the practicality of the preliminary guidelines and recommendations developed in Phase A.

4.5.1 Survey Plan

A preliminary survey plan was prepared and submitted in Phase A in response to Task Item A-4. The plan was modified at the beginning of Phase B to allow for smaller discussion groups in workshops and more participation on the part of the attendees. Provision was also made for response by letter or telephone.

4.5.2 Preparation

A review draft of proposed guidelines and recommendations, as developed in Phase A, was printed in sufficient quantity for distribution to all interested parties. A list was prepared of organizations and individuals to be invited to participate in the survey. The list of invitees included representatives from government, industry, labor unions, insurors, suppliers, utility companies, traffic controllers, environmentalists, and various interested institutions and individuals.

A letter of announcement was sent to each of the invitees, explaining the purpose of the study, and inviting each recipient to participate by reviewing copies of the proposed guidelines and recommendations and attending a workshop if possible. Those unable to attend a workshop were asked to submit written comments on the proposed guidelines, or to comment by telephone.

Response to the announcement letter was encouraging. Of 330 letters mailed, approximately 50% of the contacts responded, expressing

interest in receiving copies of guidelines and recommendations. At least 30% of those who responded showed an interest in attending a workshop discussion. Copies of the proposed guidelines and recommendations were sent to interested parties, and telephone contacts were made to key invitees who did not respond. Telephone contacts were also made to give details of the workshops.

4.5.3 Workshops

Three workshops were planned for the purpose of discussing the proposed guidelines and recommendations. The investigators chose Washington, D. C., New York City, and Los Angeles in which to hold the workshops. Major underground rapid transit systems have been built or are currently under construction in two of those cities, with the third choice made to accommodate contractors and designers on the west coast. The workshops were structured so that, after a brief introduction by the investigators, the group separated into two sections, Safety and Environmental Impact. Each guideline and recommendation was introduced by the chairmen, and participants were invited to discuss the strengths and weaknesses of each proposal, and to offer suggestions for improvement.

a. Washington, D. C. -- the Washington, D. C. workshop was held on November 22, 1975, at U. S. Department of Transportation headquarters. A total of 32 attended the workshop, 22 in the Safety meeting, and 10 in the Environmental meeting. Discussions were vigorous in both meetings and a number of valuable comments were received. As the investigators had hoped, this workshop brought together a sizeable showing of representatives from government, as well as labor unions, industry, and insurance companies.

b. New York City -- the New York City workshop was held November 3, 1975, at the United Engineering Center. A total of 17 attended the workshop, 12 in the Safety meeting, and 5 in the Environmental Impact meeting. Lively participation by government, industry, transportation, insurance, labor union and utilities representatives provided a valuable contribution to the survey.

c. Los Angeles -- the Los Angeles workshop was held as scheduled on January 14, 1976, at the Beverly Hilton Hotel. Fourteen attended, 10 in the Safety group and 4 in the Environmental Impact meeting. Attendance and participation were satisfactory and again encompassed a broad range of attendees with various perspectives regarding safety and environmental impact.

4.5.4 Additional Response

About 12 respondents submitted written comments respecting the proposed safety guidelines and recommendations. Several interested

parties who had not attended the workshops, but who had heard about the workshops and seen copies of the guidelines and recommendations, offered comments by telephone. As a follow-up to the Washington, D. C. workshop, individuals from the Metro Insurance Administration of WMATA made several suggestions to improve the safety guidelines. All of these responses contributed valuable ideas to the survey.

4.5.5 Utilization of Information

The survey program was in all respects worthwhile. Substantial revisions were made to almost all guidelines and recommendations, resulting in more realistic implementation criteria. For example, criteria for contractor selection and insurance programs are distinctly more objective and enforceable as a result of the survey.

One recommendation was deleted, which would have called for a special license for contractors for underground construction. One guideline was added, Owner's Safety Program. Two of the original guidelines, calling for safety incentive programs, were incorporated into other guidelines.

5. SAFETY GUIDELINES

This section sets forth guidelines recommended for enhancement of safety in urban rapid transit tunnel construction. They are structured so that, for the most part, they can apply to all underground construction. As noted in the preceding section, these guidelines are not intended as a "stand alone" safety method, but rather are to be applied in conjunction with applicable construction safety regulations to provide a systems approach to safety.

5.1 SUPPLEMENTAL DISCUSSION ON GUIDELINES

This subsection contains comments and references pertaining to the guidelines.

5.1.1 Owner's Responsibility

a. Guideline No. 1 -- the owner's wholehearted support is a fundamental necessity for any safety program to be successful. Much of the material for this guideline was derived from experience gained during construction of two major urban rapid transit systems, BARTD and WMATA.

b. Guideline No. 2 -- it was shown in Section 2 that 10% of the jobs accounted for the upper half of the frequency distribution. Elimination of those few contractors who continue to be irresponsible would significantly improve safety statistics. Reduction of one of every ten contractors would not appreciably affect competition, nor would it appreciably affect cost when all insurance costs are taken into account. Savings from low bids by unsafe contractors would likely be offset by increased insurance costs to the owner.

It should also be noted that one of the most compelling motivations in our present contracting system is loss of business.

Criteria for disqualification stated in Guideline 2 are considered workable; however, the search should continue for a better measure of safety performance. Criteria used should be impartial, clearly understood by owner and contractor alike, and straightforward in its method of calculation and application.

c. Guideline No. 3 -- most people look upon anything that does not have to be paid for as a "free good," and often abuse the privilege. The investigators feel strongly that the contractor should stand to gain or lose according to his safety performance.

d. Guideline No. 4 -- it was shown in Section 2 that the frequency rate for lost time accidents for WMATA changed significantly when 23

underground construction contracts were simultaneously active. The Population Division of the Census Bureau provided data on the population and male labor force in the Washington, D. C. metropolitan area. Ratios of population to the figure of 23 contracts were taken as shown in the following table:

Population July 1, 1973	3,041,800	Number of contracts Million population	7.56
Male labor force 1970 Census	769,716	Number of contracts Million labor force	29.88

It is recognized that other factors are important, and must also be considered in system planning; however, it is suggested that as a starting point, limitation of the number of simultaneous underground construction contracts to 7.5 per million total population, or 30 per million male labor force be considered.

It must be emphasized that the statistical base supporting this suggestion is limited to the construction of only one system in one metropolitan area; further, that metropolitan area happens to be the National Capital. Qualifications of the labor force may not be representative of conditions found in other metropolitan areas. Therefore, the suggestion should be used only as a starting point. The rate of recordable accidents should be continuously monitored, with countermeasures taken if an increase in trend is observed.

e. Guideline No. 5 -- owners of urban transit systems, being authorities or government agencies, are usually constrained to U. S. Government securities for short term investment of surplus funds. Returns on such investments are typically 2% below the prime rate of interest. Contractors, on the other hand, must pay a premium above the prime rate for short term financing at the start of a project. This may range upward from about 2% above the prime rate. The spread between the owner's and contractor's time value of money is therefore at least 4%.

A typical investment in tools, plant, and equipment for a large underground construction is $1,000,000. Taking a reasonable assumption of one year for the contractor to reach the break-even point, gives a $40,000 spread between the owner's return and the contractor's cost.

Adequate mobilization payments not only reduce costs to the owner, but more importantly, reduce the contractor's incentive to cut corners on his initial investment, often to the detriment of safety.

5.1.2 Designer's Responsibility

a. Guideline No. 6 -- Reference 13 contains a useful check list of procedures to be followed during core-drill investigation (pp. 167-68).

Appendix A shows the technical provisions of a specification prepared for site investigation of a waste interceptor tunnel.

b. Guideline No. 7 -- References 13 to 19 provide excellent background information on tunnel design. The Society of Mining Engineers of AIME Proceedings of the 1972, 1974, and 1976 Rapid Excavation and Tunneling conferences and the bi-monthly British publication, Tunnels and Tunnelling, are also good references. References 20 and 21 address the problem of support of adjacent structures.

c. Guideline No. 8 -- Appendix B shows a specification item prepared for the detection and control of gases for tunnels through shale known to contain localized pockets of methane and other gases.

5.1.3 Contractor's Responsibility

a. Guideline No. 9 -- some contractors have established safety programs which have proven effective. The guideline is intended as a model for those who have not yet done so, or whose safety programs require improvement.

b. Guideline No. 10 -- as part of its safety program, one contractor has developed a slide presentation depicting underground working conditions and required workman safety precautions.

5.2 GUIDELINES

Ten guidelines are recommended as a result of this study, divided into three categories according to the responsibility for implementation: owner, designer, or contractor.

Guidelines 1 through 5, dealing with owner's safety program, contractor selection, system-wide insurance programs, job scheduling, and mobilization payments, are the responsibility of the owner.

Guidelines 6 through 8, dealing with the geotechnical program, final design criteria, and natural hazards, are the responsibility of the final design engineer.

Guidelines 9 and 10, dealing with contractor's safety program and indoctrination of workmen, are the contractor's responsibilities.

OWNER'S RESPONSIBILITY

Guideline No. 1: Owner's Safety Program

Owner (Authority or Governmental Agency) of an urban rapid transit system should establish a system-wide safety program applicable to all underground construction.

Detailed Statement:

I. General Background

Many features of an underground construction safety program for an urban rapid transit system can only be undertaken by the owner. More important, the owner's direct participation is necessary to assure everyone involved that construction safety will be given due consideration "from the top down."

II. Safety Office

The owner should, as early as possible, establish an office to coordinate and manage all aspects of safety relating to construction. Functions should include:

1. Establishment and maintenance of owner's safety procedures.
2. Providing owner's safety inspection and monitoring service.
3. Recommendation and assistance in establishing a system-wide insurance program.
4. Providing owner's interface with all regulatory agencies dealing with safety.
5. Providing owner's point of communication with local police, fire, ambulance, and hospital facilities.
6. Interfacing owner's safety program with all construction contractors.
7. Providing owner's communication with news media.

III. Owner's Safety Procedures

Owner's safety procedures should be formulated early in the planning phase, and should be revised as required. Procedures should cover:

A. Operations

1. Owner's safety inspection
2. Accident reporting and statistics
3. Training
4. Guidelines for job-site tours
5. Contractor coordination

B. Regulations

1. Supplements to governmental safety regulations
2. Owner's regulations for special conditions

C. Emergency Plans

1. Accident
2. Public disorder
3. Natural disaster; e.g., earthquake

IV. Contractor Control

A. Establish contractors' minimum safety criteria for selection and award; e.g.,

1. Maximum level of recordable injuries
2. Maximum level for experience modification

B. Contract Document Provisions

1. Requirement for contractor's staff to include safety supervision and first aid attendant.

a. Contractor's candidates to be approved by owner.
b. Both safety supervisor and first aid attendant must be on duty before start of work.
c. Work must not continue more than 10 work days without safety supervisor or first aid attendant on duty.
d. Safety supervisor may not be discharged without prior approval of owner.

2. Authority for owner to have any employee removed from the Work who continually and deliberately violates safety requirements.

C. Require contractors to participate in system-wide safety meetings and training programs.

V. Insurance Program

Owner should establish the construction insurance requirements and program during the planning phase, in accordance with provisions of Guideline No. 3, Insurance Programs

VI. Owner's Safety Incentive Award Program

Owner should establish a program to recognize contractors and individuals who have made significant contributions to underground construction safety.

A. Small contractors (less than 100,000 employee hours per year)

Contractor who completes a project without a lost time injury with more than 2,500 employee hours should receive a letter of commendation from the owner.

B. Large contractors (more than 100,000 employee hours per year)

Owner should establish a scale of incentive awards according to employee hours worked without lost time injury, such as shown in the following example:

100,000	- Letter of commendation
250,000	- Certificate of merit
500,000	- Certificate of excellence
750,000	- Superior award certificate
1,000,000	- Owner's system safety trophy and certificate of honor

C. Individual Awards

Owners should provide for recognition and award to individuals who have made an outstanding contribution to underground construction safety. This should be open to anyone involved in system construction; e.g., employees of contractors, designers, consultants, or owner's staff. The nature of the commendation or award should depend on the individual's contribution.

OWNER'S RESPONSIBILITY

Guideline No. 2 - Contractor Selection

General Statement:

Contractor selection and award of contract should be based on acceptable safety record in addition to lowest bid.

Detailed Statement:

I. Objective

The objective of this guideline is to restrict bidding to those contractors who have demonstrated acceptable levels of safety in past work.

II. Prequalification

Prequalification of contractors prior to issuing invitations to bid is recommended in order to screen unqualified contractors and to help avoid disputes and delays which might otherwise arise as a result of disqualification following receipt of bids.

Criteria for qualification should be clearly established by the owner at the onset of the construction programs. Safety considerations for disqualification can include:

A. Rate of recordable injuries for contractor's most recent job exceeding the average for the industry by a factor to be established by the owner; e.g., a factor of 1.5 might be used for underground construction.

B. Most recent Experience Modification issued by the National Council on Workmen's Compensation exceeds the limit to be established by the owner.

III. Joint Ventures and Prime - Subcontractor Relationships

A. The prequalification criteria stated above should apply to the sponsor of a joint venture, with the contractually binding provision that the sponsor provide the project manager and the safety supervisor for the job.

B. Prequalification criteria stated above should apply to the prime contractor. In addition, the owner should approve all significant subcontractor selections, according to the same prequalification criteria noted above.

OWNER'S RESPONSIBILITY

Guideline No. 3 - Insurance Programs

Insurance programs should be structured so that contractors will have an incentive to maintain favorable safety records.

Detailed Statement:

I. General Background

It is recognized that a system-wide insurance program provides definite advantages to the owner, and may be the only practical method of assuring compliance by a large number of contractors and subcontractors. In addition, the owner is in a position to negotiate favorable rates because of high volume of business. However, when the owner pays for insurance and the contractor accepts coverage at no cost, there is no gain which can accrue to the contractor as a result of safe performance. Furthermore, he does not usually suffer as a result of unsafe performance.

II. Recommended Procedure

The owner should specify the insurance requirements and program for the overall system, including workmen's compensation, general liability, and builder's risk. The owner should negotiate a system-wide contract or agreement such that there will be a common carrier for all contractors; e.g., a "designated carrier." The system-wide insurance agreement should be structured so that participating construction contractors stand to gain or lose as a result of their safety performance. In each of two alternatives, the owner designates the insurance carrier and the contractor pays his own insurance premium at discounted rate resulting from system-wide agreement. Differences between the two alternatives are:

A. Contractor's rate is based on latest Experience Modification issued by the National Council on Workmen's Compensation.

B. Contractor participates in the workmen's compensation program, with payments made according to a predetermined scale. Credits or (debits) are payable or (assessed) to the contractor according to his safety performance.

OWNER'S RESPONSIBILITY

Guideline No. 4 - Scheduling of Jobs

Individual construction contracts within an overall system should be scheduled so that the pool of available workmen will not be exhausted.

Detailed Statement

I. Justification

There is evidence to indicate that the lost time injury rate increases when the level of construction activity in a major system, as approximated by the number of simultaneous active jobs, increases to the point where there is no longer an adequate pool of skilled workmen available to prosecute these jobs.

II. System Scheduling

The owner, in the system planning phase, should identify the number of separate contracts, their schedule, and the approximate labor requirement by trade, for each contract.

III. Coordination

The owner should coordinate with other agencies to obtain projections for the extent of underground construction, not only in the local and regional area, but also nationwide, during the same time period. The projections should consider:

1. Sewer and waste water tunnels
2. Water supply tunnels
3. Power plant cooling or pumped storage tunnels or other underground chambers
4. Railroad and highway tunnels
5. Subway transit systems scheduled for concurrent construction in other cities.

IV. Labor Resources Estimate

The owner should estimate as well as possible the projected labor resources in all trades important to underground construction. The assessment should consider local practice with respect

to the exclusive use of union labor. Trades considered should include:

1. Miner
2. Operating engineer
3. Laborer, heavy construction
4. Electrician
5. Ironworker, structural
6. Ironworker, reinforcing
7. Cement finisher

V. Schedule Reassessment and Monitoring

The owner should review the overall construction schedule, weighing expected safety problems due to project labor shortage against projected escalation of costs due to schedule stretchout.

Guideline No. 5 - Mobilization Payments

Mobilization payments to contractors should be sufficient to enable the procurement of tools, plant, and equipment of the caliber needed to ensure safe construction.

Detailed Statement:

I. Justification

Contractors should invest in tools, plant, and equipment capable of coping not only with design conditions, but also with those unexpected situations which could be anticipated. Since such investments must usually be made at contract award and since time cost of money is lower for the owner than for the contractor, the owner stands to gain not only in bid cost, but also in reduction of accidents, delays, and claims.

II. Basis for Payment

A. Mobilization payments made under this provision should be justified either by including a specified mobilization item in the specifications and bid items, or by review and approval of a contractor submittal.

B. Payment should require submission of proper vouchers and invoices by contractor showing that purchase of tools, plant, and equipment has indeed been made.

DESIGNER'S RESPONSIBILITY

Guideline No. 6 - Geotechnical Program

A geotechnical program should be conducted for each underground construction project, with emphasis on aspects relating to safety, both of workmen and of the Work.

Detailed Statement:

I. Justification

Numerous mishaps, often resulting in injuries or fatalities as well as damage to the Work, have resulted from encountering unanticipated subsurface conditions. The objective of this guideline is to ensure that the contractor is apprised of all pertinent information relating to subsurface conditions which can be made available within the owner's budgetary limitations for investigation and design.

II. Requirements

A geotechnical program should be conducted in conjunction with the design of each underground construction job. As a minimum, this program should identify and describe:

A. Area geological setting, including tectonics
B. Detailed ground conditions
C. Potential gassy conditions
D. Subsurface water conditions
E. Utilities and structures affected by contemplated construction.

III. Hazards

The subsurface exploration program should be conducted so that no additional hazards to subsequent underground construction are inadvertently created; e.g.,

A. No borehole should penetrate the projected tunnel alignment.
B. No borehole should permanently connect independent aquifers.
C. All boreholes should be plugged and sealed.

IV. Documentation

A geotechnical report should be prepared and made a part of the contract documents.

A. The report should include:

1. All available geotechnical data or specific reference to its existence.
2. Location and availability of such data.
3. The design engineer's interpretation of the data as applied to the design and anticipated construction problems, including the following items:

a. Descriptions of methods or sequences of construction assumed in the design, or for which the design is applicable.
b. Prediction of ground behavior germane to construction.
c. Warning of hazards to underground construction.
d. Description of required and recommended safety measures.

B. The "Differing Site Conditions" clause contained in Government Construction Contracts Standard Form 23-A, or an equivalent changed conditions clause, should be part of the contract documents.

DESIGNER'S RESPONSIBILITY

Guideline No. 7 - Final Design Criteria

Final design criteria relating to safety should be established, and should apply to each underground construction job.

Detailed Statement:

I. Objective

The objective of this guideline is to indicate areas wherein the final design and structure of the contract documents can contribute to a reduction in construction mishaps.

II. Support of Nearby Structures

Final design and contract documents should consider support requirements for all nearby structures; e.g., buildings, utilities, or other subsurface construction, which could be affected during underground construction. As a minimum, considerations shall include:

A. Structures above or adjacent to underground construction
B. Support requirements
C. Methods for achieving support
D. Effects of dewatering.

III. Ground Cover Requirements

Final design and contract documents should consider the requirements for minimum ground cover over underground structures. As a minimum, considerations shall include:

A. Dimensions and placement of underground structure
B. Engineering characteristics of ground over structure
C. Maximum permissible subsidence at surface over structure.

IV. Pillars Between Adjacent Tunnels

In the case of parallel tunnels or adjacent underground structures separated by a pillar, the final design and contract documents should, as a minimum, consider:

A. Lateral forces exerted on the pillar during construction; e.g., by a tunnel boring machine

B. Ground loads exerted on the pillar following excavation and prior to placement of final lining in either or both of the adjacent structures

C. Pillar width; i.e., spacing between structures

D. Minimum distance (along alignment between headings for adjacent tunnels when both are driven simultaneously)

V. Mixed Face

Final design of underground structures in proximity to an interface between soft ground and rock should be such that the extent of mixed face construction is a minimum.

VI. Final design and contract documents should, whenever possible or required, provide for:

A. Alternative means of access and retreat

B. Places of refuge.

DESIGNER'S RESPONSIBILITY

Guideline No. 8 - Natural Hazard Identification

Contract documents should identify and define potential natural hazards as well as specify minimum requirements for conduct of work in presence of anticipated hazards.

Detailed Statement:

I. General Background

Serious mishaps causing injuries, fatalities, and damage to the work have been associated with the presence of flammable or toxic gases, flooding of the excavation, severe storms, or earthquakes.

II. Flammable or Toxic Gases

When there is reason to anticipate that flammable or toxic gases could invade the underground work, the following minimum considerations should be included in the contract documents:

A. Identification of all known or possible sources of gases in general area. Note that, in addition to natural emissions, seepage from gas lines, sewers, and abandoned partially filled naptha or gasoline storage tanks are threats in urban areas.

B. Description in detail of all gases encountered in subsurface exploration program.

C. Specification of required inspection and testing program for gases to be followed during construction.

1. Location

Inspection and tests for gases should be made throughout the underground excavation, even where no work is being done. Special attention should be given to:

a. The working face
b. High places where light gas could rise
c. Low places where heavy gas could settle

d. Exploring forward of the working face, by means of exploratory drill holes, when gas has been detected at the face or when specified as a result of encountering gas in the subsurface exploration program.

2. Time requirements for testing:

a. Beginning each work shift
b. As specified during work shift
c. Following blasting (drill and blast excavation)
d. Continuously at face (tunnel boring machine)
e. When holing through.

D. The full extent of underground openings should be ventilated, whether worked or not, to prevent inadvertent accumulations of gas.

III. Groundwater

When it is anticipated that groundwater may invade the underground work in quantities sufficient to be hazardous, the following minimum considerations should be included in the contract documents:

A. Description of the aquifer(s)

1. Permeability (or transmissibility)
2. Storage coefficient
3. Recharge sources
4. Barrier boundaries.

B. Description of groundwater

1. Temperature
2. Dissolved minerals
3. Impurities, including potential adverse chemical reactions.

C. Effect on ground characteristics

1. Potential flowing or squeezing ground
2. Potential invert heave
3. Piping in ground material.

D. Permissible dewatering

1. Allowable subsidence of ground
2. Lead time to dewater
3. Maximum permissible spacing of dewatering units.

E. Possible alternatives to dewatering

1. Compressed air construction
2. Slurry trench construction
3. Freezing
4. Grouting.

IV. Severe Storms

When the configuration of underground construction, including location of portals or access shafts, is such that workmen or the work could be endangered by a flash flood, electrical storm, or tornado, the contract documents should require the contractor to develop and implement plans for early warning, evacuation of the work, or other precautionary action.

V. Earthquakes

When the location of the underground construction is in an area of high seismic risk, the contract documents should require the contractor to develop and implement an earthquake emergency plan.

CONTRACTOR'S RESPONSIBILITY

Guideline No. 9 - Contractor's Safety Program

Each contractor engaged in underground construction should establish a safety program responsive not only to the needs of management, but also to the requirements of each job.

Detailed Statement:

I. General Background

Some contractors have effective safety organizations both within their corporate structure and on individual jobs. The purpose of this guideline is to delineate a program which should be used by each contractor engaged in underground construction.

II. Safety Office

Each contractor with three or more underground construction jobs should establish a safety office reporting directly to the management of the firm, and should be independent of project management for any particular construction job. This office should coordinate with management to set policy, provide safety consulting and training within the company, and monitor individual construction jobs.

III. Project Safety Supervisors

A. Qualification

The project safety supervisor should have specialized training and experience in construction safety supervision and have a working knowledge of all U. S. Department of Labor (OSHA) regulations. It is highly desirable that he be a Certified Mine Rescuer. He should have the ability to develop and conduct safety training courses. He should be familiar with industrial hygiene equipment and testing as required for the protection of all employees. The safety supervisor should be employed exclusively for the purpose of supervising the safety of persons on or about the work and property affected thereby.

IV. Project Safety Program

A. Training

1. All employees should receive indoctrination relative to the particular construction project, and to the details of their individual job, including tools, plant, and equipment to be used, as described in Guideline No. 10.

2. Safety meetings at the supervisory level should be held monthly as a minimum. The agenda should include material relating to new developments in construction safety, latest changes in laws and regulations, and pertinent topics relating to the project at hand.

3. All crews should have tool box (lunch box) safety meetings weekly, as a minimum. An outline or agenda should be prepared in advance for each such meeting as a means of curtailing non-productive meetings.

4. Each supervisor assigned to the project should attend and participate in a minimum of one tool box safety meeting per month. The project manager should personally participate in at least one such meeting each three months.

B. Inspection

1. The safety supervisor should visit the work daily, or more often as required. Such visits should not follow a pattern regarding time or shift.

2. A written action form should be devised and used to document any unsafe condition or practice noted. The safety supervisor should immediately advise the project manager who would normally assign the corrective measures to a supervisor, who should sign the action form when the hazard is corrected and return the action form to the safety supervisor. The action file should be maintained in the company safety office until completion of work on the project.

C. Safety Committee

1. A safety committee should be formed which should include representation from:

a. Project manager
b. Project supervision, including "walkers"
c. Project safety supervisor
d. Foreman, or "shifters"
e. Owner, or resident engineer.

2. The safety committee should meet monthly, or more often as required.

3. The safety committee should create a log of action items which shall include all unsafe conditions pertaining to the work.

4. Assignments, with due dates, for corrective action should be made.

5. All items should remain on the log as old business until corrective action is completed.

D. Safety Incentive Program

The contractor should establish a safety incentive program for each project. The program should recognize contribution of crews and foremen, and should establish criteria and rewards.

1. Criteria could include:

a. Evaluation period; e.g., monthly
b. Fewest accidents
c. Minimum lost time
d. Sustained safe performance over a number of evaluation periods; e.g., 6 or 12 months.

2. Rewards could include:

a. Recognition
b. Paid social events; e.g., dinner parties for crews and escorts. (Consideration should be given to possible liability to contractor if alcohol is served.)
c. Monetary reward; e.g., wage premium for next evaluation period.

CONTRACTOR'S RESPONSIBILITY

Guideline No. 10 - Indoctrination of Workmen

Before being assigned underground, all workmen should receive indoctrination in the nature of underground work and to the details of the job and their particular assignment.

Detailed Statement:

I. General Background

Indoctrination to job conditions is particularly important in underground construction because of the peculiarities of the work site; e.g., limited space, noise, fog, and machinery movements. Conduct of an indoctrination program is further complicated by frequent additions of inexperienced personnel to the work force. It is therefore important that indoctrination for new hires be both effective and rapid.

II. Pre-job Conference

Contractor's project manager and safety supervisor should meet with local labor organizations before work starts to describe project, job requirements, working conditions, and to establish areas of cooperation with respect to safety.

III. New Hires

A. New hires with no previous underground work experience should receive an indoctrination which includes as a minimum:

1. Description of general working conditions, hazards, and precautions required in underground construction.
2. Description of the current underground construction project.
3. Description of the current or next phase of work on the project, emphasizing hazards and required precautions.
4. Details of the workman's immediate assignment, including descriptions of work, hazards and precautions.

B. Recommended Program

1. Brief sound movie depicting underground construction, noting hazards, and illustrating precautions.

2. Brief conference and tour of jobsite by contractor's safety supervisor and workman's immediate supervisor.

3. Assign new hire to work with an experienced workman; e.g., buddy system, at least one month.

4. Follow up observation of new hire both by job supervisor and safety supervisor during first six months on job.

C. New hires with previous underground work experience should receive a mimimum indoctrination which should include:

1. Introduction to job supervisor and safety supervisor.

2. Brief description of current project.

3. Description of the current or next phase of work on the project, emphasizing hazards and required precautions.

4. Details of the workman's immediate assignment, including descriptions of work, hazards, and precautions.

IV. All Workmen - New Work Phase

A. All workmen, regardless of experience, should receive an indoctrination before starting a new underground construction job, or before starting a new phase of work; e.g., changing from excavation to placing concrete lining. Such indoctrination should include:

1. Description of forthcoming work, emphasizing hazards and required precautions.

2. Details of work assignments, including descriptions of work, hazards, and required precautions.

6. SAFETY RECOMMENDATIONS

The recommendations listed in this section, if implemented, would work in conjunction with the guidelines shown in Section 5 and established safety regulations; e.g., OSHA 29CFR1926 Subpart S, to provide a comprehensive safety system for underground construction.

A clear distinction should be made between safety guidelines and safety recommendations discussed in this section. As noted in Section 4, recommendations include those items needed to complete the systems approach to tunnel construction safety, but which are not ready for implementation.

The first recommendation should be the responsibility of state agencies currently licensing professional engineers.

Three recommendations, numbers 2 to 4, should be the responsibility of Federal research and development agencies. They could be supported by any interested agency, as an in-house effort, by contract, or by a supporting grant to an appropriate organization.

Four recommendations, numbers 5 through 8, should be the responsibility of Federal regulatory agencies. The safety academy recommended in number 5 could be established and operated by any interested party; however, since Federal support would likely be required, it is listed in this category. Recommendations 6, 7, and 8 should be in-house activities of a Federal agency.

The final recommendation, number 9, does not lend itself to classification with any of the other items. Therefore, it is listed separately.

Recommendation No. 1 - Underground Construction License

Programs should be established for the qualification, examination, and licensing of supervisors, inspectors, and selected workmen specializing in underground construction.

Detailed Statement:

I. Licensing should be a state function, consistent with the practice of state licensing for professionals, and should take the form of an individual registration, certification, or license in accordance with the practice of the state.

II. All aspects of underground construction should be included in qualification and examination, with emphasis on safety.

III. General Requirements

A. Eight years of qualifying experience. Experience should be on full time basis, except for equivalents listed below.

B. At least two years full time experience working underground as supervisor, inspector, or foreman.

IV. Experience Equivalents - Substitution may be made toward the eight year experience requirement only according to one of the following:

A. Six years' credit for registration as a professional engineer in any state in civil, mining, or structural engineering.

B. Four years' credit for successful completion of an Engineer-in-Training written examination in any state in the United States.

C. Five years' credit for a masters or higher civil engineering degree from a school whose undergraduate degree is accredited by Engineers' Council for Professional Development (ECPD).

D. Four years' credit for a B. S. degree in a civil engineering curriculum accredited by ECPD.

E. Four years' credit for current registration as a Certified Mine Rescuer by the U. S. Bureau of Mines.

V. Functional Area Requirements - Accomplishment should be shown in at least two of the following four functional areas:

A. Initial support and ground control
B. Control of underground water
C. Compressed air tunneling
D. Control of flammable or toxic gases

Recommendation No. 2 - Safety Standards for Equipment

Minimum safety standards should be established governing the design, fabrication, installation, test, acceptance, and field modification of all tools, plant, and equipment used in underground construction.

Detailed Statement:

I. A study should be made to determine the detailed requirements for safety standards for all tools, plant, and equipment used in underground construction. Recognized techniques such as failure mode and effects analyses should be used. This study should be followed by development of safety standards.

II. Safety standards applicable to design of tools, plant, and equipment should include the following considerations:

A. Personnel protection

1. Operator
2. Other workmen

B. Materials

C. Assembly, especially:

1. Welds
2. Fasteners
3. Anchorage devices

D. Hoisting or lifting attachments

E. Limitations on field modifications

III. Safety standards applicable to fabrication, test, and acceptance should include:

A. Certification of materials

B. Welds and fasteners

C. Lifting and anchorage devices.

IV. Safety standards applicable to field modification should include:

A. Requirement for engineering analysis and design of modification and acceptance of responsibility by licensed professional engineer.

B. Requirements for inspection and test during field modification.

C. Limitations to use following field modification.

D. Limitations on re-use or subsequent modification.

V. All standards developed under this recommendation should be enforceable.

Recommendation No. 3 - Alternative Designs for Equipment

Alternative designs for safety features of tools, plant, and equipment to be used in underground construction should be developed and published so as to be in the public domain.

Detailed Statement:

I. Alternative detailed designs for tools, plant, and equipment should be prepared and published, according to the following considerations:

A. Standards developed under Recommendation No. 2 should apply.

B. At least two alternative designs should be prepared and published.

II. Prototypes should be fabricated according to design and tested prior to publication. Test results should be published with designs.

III. Provisions should be instituted for initiating revised designs and for preparing designs according to new concepts as they arise.

Recommendation No. 4 - Compressed Air Regulations

Compressed air regulations governing hours of work, medical lock, attendants, physician availability, and decompression schedules should be re-evaluated.

Detailed Statement:

I. Requirements for physical examination and medical record-keeping should be modified.

A. The first pre-work physical examination should include x-rays, and should be sufficiently comprehensive to establish a baseline for subsequent medical evaluation and for physiological research; however, the examination should not be more detailed than required for the working pressure.

B. Subsequent physical examinations including x-rays should, as a minimum, be made annually so long as the individual is continuously working under compressed air.

C. Medical records should be archived for all persons who have worked under compressed air. This should be done by a center already established for maintaining medical records.

II. Medical locks should be designed to a working pressure of 90 psig.

III. Requirements for medical lock, medical attendance, and emergency medical facility should be modified when the working pressure does not exceed 12 psig.

A. A medical lock must be available within the local area, but need not be located on the construction site.

B. The project physician should be continuously on call when the work is pressurized, and should visit the site at reasonable intervals.

C. A first aid attendant should be on duty at all times when workmen are under compressed air and for a period of 8 hours following decompression, and he should be especially indoctrinated in first aid requirements for compressed air work.

D. No emergency medical facility, beyond a fully equipped first aid station, should be required.

IV. Hours of work within each 24-hour period should be adjusted so that the sum of the working period and decompression time is approximately 8 hours, according to the following table:

Working Pressure psig	Working Period Hrs Min	Work Shifts Per Day	Total Decompression Time Minutes	Total Time Working and Decompression Min	Hrs-min
0 -12.00	8.0 480	3	3	483	8 - 03
12.01-24.00	8.0 480	4	122	482	8 - 02
24.01-34.00	4.8 288	5	195	483	8 - 03
34.01-44.00	4.0 240	6	244	484	8 - 04

V. Research should be conducted on the physiological aspects of work under compressed air and should include as a minimum:

A. Revision of work and decompression schedules applicable above 34 psig. This is of prime importance since recent medical experience has uncovered problems when working in 42-44 psig range under existing regulations.

B. Re-evaluation of decompression schedules in the 12-34 psig range and at high altitudes.

C. Development of physiological data needed to establish evaluation of working hours and decompression schedules at high altitudes.

Recommendation No. 5 - Safety Academy

An academy should be established for the training of specialists in underground construction safety.

Detailed Statement:

I. An Underground Construction Safety Academy (UCSA) should be established and operated or subsidized by the Federal government.

A. The UCSA should fulfill requirements for specialized training for all tunneling and underground construction, except as related to mining.

B. The UCSA should include a mobile facility, so that instructions can be given on or near the owner's site for major projects such as transit systems.

II. Curricula should be established for the following categories:

A. Project managers and superintendents

B. Supervisors and inspectors

C. Safety supervisors

D. Specialized courses for selected workmen; e.g.,

1. Blasting and explosive handling
2. Detection and control of flammable or toxic gases.

III. Curricula should include, as a minimum:

A. Identification of hazardous conditions

B. Methods of eliminating or reducing hazardous conditions.

C. Methods for working safely in presence of uncorrectable hazards.

D. Methods for maintaining workmen's attention toward safety.

Recommendation No. 6 - Safety Data Collection

Data concerning each underground construction mishap should be compiled and forwarded to a central collection and analysis agency.

Detailed Statement:

I. Requirements - Data shall be gathered pertaining to all accidents causing personal injury, fatality, or damage to property in excess of $2,500.

II. Scope - The following items shall be tabulated, as applicable, for each mishap:

A. Task being accomplished

B. Description of mishap

1. Detailed description
2. Location of mishap
3. Personal injuries or fatalities
4. Damage to property

C. Equipment involved

1. Type
2. Manufacturer
3. Model
4. Age
5. Maintenance history, including time since last maintenance and details of last maintenance.

6. Field modifications, including dates and details of modifications(s).

D. Workmen

1. Total underground experience
2. Experience at this task
3. Experience with this equipment
4. Age
5. (For compressed air work only) Any unusual activity or additional decompression involving altitude changes greater than 5,000 feet, e.g., airplane flights.

E. Description of accidents involving fatalities

1. Narrative
2. Graphical, including photographic coverage
3. Comments regarding how accident might have been avoided.

Recommendation No. 7 - Safety Analysis Center

A center should be established for the purpose of archiving and analyzing data respecting underground construction mishaps.

Detailed Statement:

I. A Safety Analysis Center (SAC) for underground construction should be established within an existing government agency and operated by the Federal government.

II. Functions of the SAC should include:

A. Archiving safety data regarding underground construction

B. Preparation and maintenance of manageable data base

C. Analysis and reporting of underground construction safety data should include:

1. Periodic reports of underground construction safety
2. Safety data relating to tools, plant, and equipment
3. Safety data relating to work task
4. Safety data relating to worker's experience
5. Safety data relating to mishaps affecting nearby property.

D. Preparation of contractor's safety ratings (see Recommendation No. 8).

Recommendation No. 8 - Contractor Safety Ratings

Safety performance ratings should be developed for each contractor engaged in underground construction and after hearing evidence in support of modification, should be made a matter of public record.

Detailed Statement:

I. Safety performance ratings should be developed for each contractor engaged in underground construction.

A. Ratings should be developed by the safety analysis center described in Recommendation No. 7, if the SAC is operational. Otherwise, each interested government agency should develop its own system.

II. Ratings should include:

A. Incidence of recordable accidents on each contractor's current and three most recently completed underground construction jobs as well as for current year and two prior years.

III. Uniform system of safety performance rating should be established and should consider:

A. Contractor's most recent work

B. Diminished importance of work done more than two years previously

C. Applicability to both large and small contractors, or alternatively, classification of contractors into categories.

D. One possible scheme is to assign:

Factor of 0.5 to last full year's work
Factor of 0.3 to year before
Factor of 0.2 to previous year.

IV. Contractor's Hearing

A. Each contractor should be formally advised of his proposed rating.

B. Each contractor should be given opportunity to present evidence in support of any requested modification.

C. Contractor's evidence should be considered by an impartial body.

D. Each contractor should have the right of court challenge.

V. Publication

A. Following resolution of contractor challenges, ratings should be published and made a matter of public record.

B. Interim or tentative ratings may be published prior to resolution of challenge, so long as they are clearly designated as tentative.

Recommendation No. 9 - Reward for Safety Patents

A program should be established such that independent inventors can expect adequate compensation for patents awarded for safety features or devices.

Detailed Statement:

I. This program should be restricted to individual inventors who receive no other compensation for work leading to a patent to be considered for reward.

II. Patents to be considered should be limited to safety enhancement in underground construction in the following areas:

A. Construction methods
B. Tools, plant, and equipment
C. Initial support devices

III. The patented invention should be in use with demonstrated results before the inventor receives benefits.

IV. The Federal government should implement this program either through an existing department or agency or by subsidy through a trade association or professional society. The reward offered for safety inventions should be adequate to attract competent inventors.

7. IMPLEMENTATION OF GUIDELINES

This section discusses aspects of implementation of the recommended guidelines, including an evaluation of priorities, methods for monitoring and control, and an estimation of cost.

7.1 PRIORITIES

Each of the 10 guidelines stated and described in Section 5 is intended to contribute to the enhancement of safety in underground construction. All of these in conjunction with existing construction safety regulations; i.e., 29CFR1926, make up an integrated package. In this respect, they should all be implemented immediately. This is impractical, since owners who are constructing or planning to construct urban transit system tunnels are in differing phases of their development. It should be noted that three of these guidelines could be implemented by designers and two could be implemented by contractors immediately without additional approval. Therefore, one should not attach undue importance to a ranking of guidelines. The following ranking represents the investigators' subjective evaluation of relative importance.

Guideline Number	
1	Owner's Safety Program
2	Contractor Selection
10	Indoctrination of Workmen
9	Contractor's Safety Program
4	Scheduling of Jobs
3	Insurance Program
8	Natural Hazard Identification
6	Geotechnical Program
7	Final Design Considerations
5	Mobilization Payments

7.2 MONITORING AND CONTROL

No safety program, however carefully structured, will be effective unless adequate steps are taken to monitor and control the work. Methods range from voluntary action which could be taken by the contractor or owner to forceful dealing with irresponsible individuals.

7.2.1 Methods

This subsection addresses the more important methods which can be used by owners, contractors, workmen, and regulatory agencies for improvement of safety.

a. Owner's participation -- vigorous participation on the part of the owner is a prerequisite to the success of a construction safety program. Guideline No. 1 defines the owner's responsibilities and measures which should be taken.

b. Assessment of contractor's setup with regard to minimum safety standards -- the first activity following selection of the contractor should be a meeting or meetings to assess and to approve the contractor's plans regarding safety. The assessment and approval should be comprehensive and should include:

1. Contractor's safety program -- the assessment should review the contractor's proposed program to ensure that the intent of Guideline No. 9, Contractor's Safety Program, is satisfied. The contractor's safety program for the particular construction should be specified prior to invitation to bid, and should be reviewed and approved prior to contract award.

2. Competence of contractor's proposed staff -- the assessment should review in detail the contractor's proposed project management, safety supervisor, key working staff, and training or indoctrination programs.

3. Adequacy of the contractor's proposed tools, plant, equipment, and construction methods -- the construction methods planned by the contractor, as well as his proposed tools, plant, and equipment must be able to cope with anticipated underground situations, otherwise the job is quite likely to become both unsafe and expensive, as well as delayed.

c. Contribution by work force -- it is axiomatic that no group is nearer to the safety problem than the workmen in the tunnel. The contribution of this group can manifest itself in two ways: by the establishment of an avenue of communication for the solicitation of suggestions from workmen, and by a voluntary effort, or self-discipline, on the part of the workmen to improve their own safety record.

Guideline No. 9, Parts IV A and IV C, provide a vehicle whereby workmen's suggestions and observations can become part of the safety program. Part IV D provides an incentive for crews to take voluntary measures in the interest of safety.

d. Self-monitoring by contractor -- most contracts specify that the contractor shall be responsible for safety of the work. There is much the contractor can do to fulfill this obligation. Guideline No. 9 indicates steps which can be taken by a contractor to monitor and control safety in his own work.

e. Inspection -- the final link in the methodology is monitoring, and if necessary, enforcement, by an outside organization. This should be done at two levels, that of the owner and appropriate regulatory agencies.

1. Owner -- owners have long been accustomed to monitoring and controlling the progress of their work. This function is nominally performed by the Resident Engineer representing the owner in all matters at the jobsite. In addition, transit authorities who do not have an owner's safety inspection program should implement one, as stated in Guideline No. 1.

2. Regulatory agency -- some safety inspections by regulatory agencies are currently being made. OSHA inspects construction projects in areas within their jurisdiction. States with strong industrial safety programs; e.g., California, inspect underground construction. Unfortunately, two problems currently exist with the OSHA inspection program. First, there are not sufficient inspectors to visit each jobsite as often as required for good monitoring and control; and second, inspections for underground construction are not separated from those for general construction, so that rarely does a tunnel inspector have specialized knowledge of underground construction conditions.

It is recommended that inspections by regulatory agencies be made often enough that the job progress can be monitored as opposed to spot checks, and that inspectors be qualified in underground construction as noted above.

7.2.2 Publication of Safety Records

Safety records for underground construction should be made a matter of public record, in a manner similar to profit and loss statements and contract awards. If not published in a trade magazine; e.g., Engineering News Record, then they should be published in an official government publication. The safety records should be tabulated and published according to the following breakdown:

a. For each contractor engaged in underground construction

b. For each major project involving a high content of underground construction

c. By geographic or metropolitan area.

7.2.3 Handling Safety Offenders

Handling of offenders in any discipline is a punishment problem, and safety in tunnel construction is no exception. In establishing the following rationale, the distinction between representatives of regulatory agencies and owners or contractors must clearly be made. The investigators believe that representatives of regulatory agencies are adequately compensated and have an obligation to the public to be both vigorous and fair in their dealings. By contrast, an inspector working for an owner or contractor may find his employer's interests in strong conflict with safety. It can therefore be understood that such individuals may experience strong pressures from their employers which would not be expected within a regulatory agency. Therefore, the investigators have distinctly less sympathy with offenders employed by regulatory agencies than with offenders employed by owners or contractors.

The difference in handling of offenders as recommended differs as shown in the following subsections.

a. Regulatory agency representatives -- it is recommended that the handling of offenders within regulatory agencies be immediate. This follows from the philosophy that if a safety program is to be effective, the representatives of regulatory agencies must be honest, fair, and competent. The recommendations are, therefore, as follows:

1. Discharge -- this course of action is recommended for those who are merely incompetent.

2. Loss of license -- this course of action is recommended for those who either are grossly incompetent, or for whom there may be serious question of their ethics, but not sufficient evidence to base conviction. This sub-item is dependent on the issuances of licenses for inspectors.

3. Fine or imprisonment -- this course of action is reserved for those who have exhibited a flagrant disregard for the responsibility and ethics of their position

b. Owner's inspectors -- a rather different rationale is recommended for offenders who are in the owner's (or contractor's) employment.

1. Establishment of a "point system" analogous to several state driver's license enforcement systems -- the objective of this item is to establish a measure from which various levels of disciplinary action may be taken.

2. Issue warnings -- this would be the first step toward serious disciplinary action.

3. Suspension without pay for prescribed terms -- this follows from the rational that the most serious sanction one can lodge against an individual, short of fine or imprisonment, is to deprive him of his normal means of livelihood.

4. Discharge and/or revocation of license -- this final action to be taken against those serious or repeating offenders is to permanently remove them from the scene of action. In the final analysis, such people have no place in underground construction!

7.3 ESTIMATE OF IMPLEMENTATION COST

This subsection discusses only the estimates of monitoring costs required for implementation of the guidelines set forth in Section 4.

Costs can generally be allocated to the following parties: owner, geotechnical consultant, design engineer, contractor, and regulatory or other Government agency.

7.3.1 Approach Used

An estimate of the total dollar cost for implementation would require a valid estimate of the projected demand for underground construction in dollars. While attempts have been made to provide such estimates (see Reference 22, for example), the investigators believe that the potential margin of error is unacceptable.

Many of the costs of peripheral activities surrounding construction; e.g., the geotechnical program, can be successfully estimated in percent of actual construction cost, or dollars per million dollars of construction. Ratios of services to construction cost used in developing cost estimates are shown in the following table:

Service	Percentage of Construction Cost	Dollars per Million of Construction
Subsurface Exploration	0.5	5,000
Design	5	50,000
Inspection	3	30,000

7.3.2 Explanation of Cost Estimates

Cost estimates and allocations for proposed safety guidelines are shown in Table 7-1. With few exceptions, cost is listed in dollars per million dollars of construction cost.

Explanation of the basis for cost estimates is as follows:

Guideline No. 1: Based on approximate figures for one transit system having undertaken major construction over the past 5 years. The cost estimate for owner's safety office is about $1,200 per million. In addition, contracting of system-wide safety inspection services is about $3,000 per million, or a total of $4,200 per million.

Guideline No. 2: If a contractor with a poor safety record bids too low, then there is a likelihood of increased cost due to lack of safety. Therefore, no additional cost penalty is assumed for imposing this guideline.

Guideline No. 3: Workmen's compensation costs now run about $30,000,000 annually, based on 4% of contract value or $40,000/M. In a few cases, rebates are now given to contractors by insurors for safe jobs; however, the amounts are not known. It is estimated that the cost could vary either up or down by a factor of 2; hence, no overall change is allocated to this guideline.

Guideline No. 4: A cost reduction is projected for each construction contract because of increased competition and efficiency of labor; however, cost increases will accrue to delayed contracts because of current inflation rates. Therefore, no additional cost is allocated.

Guideline No. 5: This guideline does not increase the cost of construction, but may decrease the value of bids received, since rising interest rates need not be considered by the contractor.

Guideline No. 6: It is estimated that additions should be made to the exploratory program to the extent of 25% for special gas analyses, 10% for groundwater analyses, and 5% for utility location. It is further estimated that 10% of the jobs will require gas analysis, 50% will require groundwater analysis, and all jobs will require utility relocation. A weighted figure of $5,635/M was therefore used for subsurface exploration. Preparation of a comprehensive geotechnical report is estimated at an additional $2,000/M. A total of $7,735/M was therefore used.

Guideline No. 7: No additional cost is allocated, since this is considered part of normal design procedure.

TABLE 7-1

COST ESTIMATES AND ALLOCATION

Guideline Number	Allocation	Cost per Million Dollars of Construction
1 - Owner's Safety Program	Owner	4,200
2 - Contractor Selection	Owner	No additional cost
3 - Insurance Program	Contractor	No additional cost
4 - Scheduling of Jobs	Owner	No additional cost
5 - Mobilization Payments	Owner	Savings to owner
6 - Geotechnical Program	Geotechnical Consultant, Designer	7,635
7 - Final Design Considerations	Designer	No additional cost
8 - Natural Hazard Identification	Designer, Contractor	1,000
9 - Contractor's Safety Office and Program	Contractor	700
10 - Indoctrination for Workmen	Contractor	500

Guideline No. 8: It is assumed that this provision would add approximately 2% to the construction cost, mostly for exploratory drilling ahead of the face. It is further assumed that about 1 of 20 tunnels will be gassy, therefore the estimate of $1,000/M. No additional cost is included for groundwater control.

Guideline No. 9: The cost varies considerably with the size of the contractor's operations and his method of doing business. One analysis shows $715/M for a large contractor with widespread operation. A figure of $700/M is used for this guideline.

Guideline No. 10: One day at $100/day for a work force of 150 was assumed for a 30 million dollar contract, for an estimate of $500/M.

7.3.3 Cost Estimates

The estimates shown in Table 7-1 total $14,035 per million dollars of construction, or less than 1.5%. This does not include costs for research, development, and operations attributable to regulatory and other government agencies. In any event, this represents a modest cost for such an important potential gain.

7.4 CHANGES CONTRIBUTING TO SAFETY

Two categories of change which could contribute to safety are identified, legislative or institutional, and traditional. Legislative or institutional action is required for implementation of several of the recommendations.

Changes in tradition are in many cases beyond the realm of regulation or legislation. However, such changes could become an important contribution to safety in underground construction.

7.4.1 Legislative or Institutional Changes

Modes of implementation range from Federal action - the most cumbersome and difficult, albeit the most permanent mode - to voluntary adoption - the simplest and quickest, but the most fragile mode.

State legislation is recommended for items which involve qualification, examination, and licensing, and those which involve changes in contract law. Historically, these have been in the domain of state government, and the investigators find no reason for recommending otherwise.

7.4.2 Changes in Tradition

The basic concept of tradition implies that it is without change. Yet, there are additions or changes to tradition in underground excavation which, if implemented, would contribute to improvement of safety. Two of these are discussed here.

a. Improve attitude of workmen toward individual safety -- workmen are closest to the scene of underground construction; yet these same workmen often display a flagrant disregard for their own well being. The solution to this problem can be approached in three ways:

1. Reduce the tendency to heroics -- the word "machismo," often used in Latin America, carries the meaning of an exaggerated sense of masculinity, stressing such attributes as physical courage, virility, and aggressiveness. This attitude is found among construction workmen, including those in tunneling and is manifested by a willing disregard for safety as an exhibit of masculinity.

It is important that this attitude among workmen be replaced with one which is essentially the opposite, and which evokes the favor or envy of fellow workmen.

2. Reduce the "end justifies the means" attitude in both supervisors and workmen -- any underground construction project is filled with moments when it is imperative to accomplish an immediate objective, and in such moments, everyone's attention is focused toward that objective. There is a tendency to forego prudence and safe conduct, and at these times, mishaps occur.

The remedy for this problem must come from top management, and be instilled throughout the ranks of supervisors. Only then will there be changes in the attitudes of tunnel construction crews.

3. Promote fashion of using properly designed personal protective equipment -- it is indeed true that personal protective equipment is disregarded on many occasions because it is uncomfortable or an impediment. It is also true that part of the problem is the tendency to heroics noted above.

Two approaches to the solution are required: First, equipment must become available which is comfortable to use, causing minimal impediment to the workmen. Given such equipment, steps must be taken to make it fashionable, or the "in" thing to use.

b. Remove or reduce taboo toward female tunnel construction workers -- the taboo toward women at the construction site has long pervaded both tunneling and mining, and to a lesser extent, all heavy

construction. In general construction, women are now accepted among the work force in several trades. Women have been allowed to visit underground in deep mines in South Africa for some time. Women are slowly being accepted in mining as part of the underground work force. Certainly, there is no reason, other than tradition itself, to continue this taboo.

1. Women tend to be more concerned about personal safety than men -- this has been established on the nation's highways, where the accident rate among women drivers is substantially lower than for men. It has also been demonstrated in factories, and in homes, possibly because women are less inclined to "heroics" as noted above.

2. Some underground construction tasks may be performed more safely by women -- women normally pay greater attention to detail, and this, coupled with increased concern regarding their own safety as well as the safety of others, contributes to the overall safety objective. Many tasks such as the operation of equipment could therefore be accomplished safely by women.

8. REFERENCES

1. Method of Recording and Measuring Work Injury Experience, ANSI Z16.1-1967 (R1973), American National Standards Institute, Inc., 1430 Broadway, New York, N.Y., 10018

2. Recordkeeping Requirements Under the Williams-Steiger Occupational Safety and Health Act of 1970, U. S. Department of Labor, Occupational Safety and Health Administration.

3. Recordkeeping Requirements Under the Occupational Safety and Health Act of 1970, U. S. Department of Labor, Occupational Safety and Health Administration, Revised 1975.

4. Occupational Injuries and Illnesses by Industry, 1972, Bulletin 1830, U. S. Department of Labor, Bureau of Labor Statistics, 1974.

5. "BLS Reports Results of Survey of Occupational Injuries and Illnesses for 1973," USDL-74-687, News, U. S. Department of Labor, Bureau of Labor Statistics, December 20, 1974.

6. Davis, I. and Harvie, A., "Report of Investigation of December 11, 1971 Accident at Port Huron Water Intake Tunnel," in: Graham, J. R., ed. (1974), Use of Shotcrete for Underground Support, Proceedings of the Engineering Foundation Conference, South Berwick, Maine, July 16-20, 1973, ACI Publication SP-45, American Society of Civil Engineers and American Concrete Institute, Detroit, Michigan, pp. 392-399.

7. Cranston, George E. (1973), The Safety Harvest from Space Programs, Cranston Research, Inc., Alexandria, Virginia, under Contract NASW-2173.

8. Pfleider, E. P. et al. (1968), Rapid Excavation - Significance, Needs, Opportunities, National Academy of Sciences, Publ. 1960, Washington, D. C.

9. Scott, J. H., and Carroll, R. D. (1967), "Surface and Underground Geophysical Studies of Straight Creek Tunnel Site, Colorado," Highway Research Record No. 185, Highway Research Board, Publ. 1516, Division of Engineering, National Academy of Engineering, Washington, D. C.

10. Tunnel Safety Orders, Division of Industrial Safety, State of California, Sacramento, California (Register 73, No. 34-8.25.73).

11. "Construction Safety and Health Regulations, 29CFR1926, Subpart S - Tunnels and Shafts, Caissons, Cofferdams, and Compressed Air," U. S. Department of Labor, Occupational Safety and Health Administration, Federal Register, Vol. 39, No. 122, June 24, 1972.

12. "How Effective is OSHA?," editorial, Engineering News Record, January 16, 1975, p. 60.

13. Wahlstrom, E. E., (1973), Tunneling in Rock, Elsevier Scientific Publishing Company, Amsterdam, London, New York, pp. 167-168, 194.

14. Proctor, R. V., and White, T. L., (1946), Rock Tunneling With Steel Supports, (Revised 1968), Commercial Shearing and Stamping Company, Youngstown, Ohio.

15. Peck, R. B., 1969, "Deep Excavations and Tunneling in Soft Ground," printed in State of the Art Volume, Seventh International Conference on Soil Mechanics and Foundation Engineering, Sociedad Mexicana de Mechanica de Suelos, A. C., Mexico City, pp. 225-290.

16. Design Manual - Soil Mechanics, Foundations, and Earth Structures, NAVFAC DM - 7, March, 1971, Department of the Navy, Naval Facilities Engineering Command, Washington, D. C.

17. Obert, L., Duvall, W. I. and Merrill, R. H. (1960), Design of Underground Openings in Competent Rock, U. S. Bureau of Mines Bulletin 587, U. S. Government Printing Office, Washington, D. C., pp. 18-22.

18. Peck R. B. et al. (1969), Some Design Consideration in the Selection of Underground Support Systems, Department of Civil Engineering, University of Illinois, Contract No. 3-0152, for U. S. Department of Transportation, pp. 8-15.

19. Szechy, K., (1970), The Art of Tunneling, Akademiai Kiado, Budapest.

20. D Applonia, D. J., (1971), "Effects of Foundation Construction on Nearby Structures," Proceedings, 4th Panamerican Conference on Soil Mechanics and Foundation Engineering, Vol. I, San Juan, Puerto Rico, pp. 189-236.

21. Ware, K. R., (1974), "Underpinning Methods and Related Movements," printed in Volume 2, Proceedings, 1974 Rapid Excavation and Tunneling Conference, Society of Mining Engineers of AIME, New York, pp. 1255-1274.

22. Meloy, T. P. and Newcomb, R. T. (1970), "United States Comments on the Report on Tunneling Demand 1960-80," Proceedings, OECD Advisory Conference on Tunneling, Washington, D. C.

23. Glantz, D. (1975), "Let's Unchain State Licensing Boards," Civil Engineering, January, 1975, pp. 79-83.

24. NASA Safety Manual, NHB 1700.1, Volume 3, System Safety, dated March 6, 1970.

25. Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (Revision 1), Regulatory Staff, U. S. Atomic Energy Commission (now Nuclear Regulatory Commission). Issued October, 1972.

APPENDIX A

MODEL SUBSURFACE INVESTIGATION SPECIFICATION

3.10 MOBILIZATION AND DEMOBILIZATION - The Contractor shall be responsible for all work required for mobilization of equipment, men and materials for this Contract. No measurement shall be made for payment for mobilization and demobilization. Payment of the first one-half of the lump sum set forth in the Schedule of Prices shall be made after drilling has started and payment of the second one-half shall be made on the date of issue of the Certificate of Completion.

The Construction area shall be kept in a neat and orderly condition during construction operations. Concurrent clean up operations shall be maintained throughout the contract period. Surplus and discarded materials scattered over roadways, lawns and sidewalks shall be accumulated and stacked or disposed of, materials necessary for subsequent construction stacked neatly at the appropriate construction site and excess excavation removed.

Should the Contractor fail to clean up the construction area each day to the satisfaction of the Engineer, this will be done by others and the cost thereof plus 10% deducted from the final payment.

3.11 ABANDONED BORINGS -

(A) Borings shall not be abandoned before reaching the final depth ordered by Engineer except on the approval of Engineer. No payment will be made for borings abandoned by reason of an accident or negligence attributable to the Contractor. Borings abandoned before reaching required depth, due to an obstruction or other reasonable cause not permitting completion of the boring by standard procedures, shall be replaced by a supplementary boring adjacent to the original and carried to the required depth. Penetration to the completed depth of the original boring may be made by any means selected by Contractor and approved by Engineer. Payment will be made for the approved portion of the abandoned hole plus that portion of the supplementary boring extending below the final elevation of the original boring. Samples shall be taken in the supplementary boring from the elevation at which the original boring was abandoned in a manner specified for the original boring.

(B) If abandoned for reasons acceptable to the Engineer, payment will be made for the boring at the appropriate unit prices

for boring and sampling stated in the Contract, provided Contractor presents soil samples and records as specified plus a report on the obstruction which necessitated relocating the boring.

(C) Blasting with small charges will be permitted for removal of boulders or other obstructions which cannot conveniently be removed otherwise, providing Contractor obtains permission therefore from public authorities and Engineer and such blasting shall be done only when and as directed by Engineer. Before blasting, the casing, if used to depth of blasting, shall be pulled up at least 8 feet to avoid damage.

3.12 DRILLING IN SOIL - Advancing a hole in overburden soil without sampling is referred to herein as drilling in soil. Drilling in soil shall include setting and sealing casing into the underlying rock so that a 3 inch diameter hole can be drilled in the rock below.

Measurement for payment for drilling in soil shall be the lineal feet of hole drilled. Payment shall be either at the unit price per lineal foot for vertical drilling or at the unit price per lineal foot for angle drilling set forth in the Schedule of Prices.

3.13 SOIL SAMPLING - The Engineer may require sampling of the overburden soil by means of a soil sampling method appropriate for the soil involved.

Measurement for payment for soil sampling shall be included in the unit price for drilling in soil set forth in the Schedule of Prices.

3.14 CORE DRILLING - The Contractor shall core-drill size NX (2 1/8" approximate diameter of core) test holes at the locations and to the depths directed by the Engineer. Angle holes shall be oriented at the direction of the Engineer. The Contractor's drilling methods shall be consistent with the best modern practice, and shall be such that the maximum recovery of core in good condition is obtained. All rock coring of NX-size shall be accomplished using a Christensen Diamond Products Co. NWD3 split inner tube core barrel or approved equal and diamond bit.

The Contractor's equipment shall be in good condition at the start of the work and shall be designed to perform the work adequately. If undue breakdowns occur or repair time becomes excessive, the Contractor shall replace the defective equipment promptly. Loss of, or damage to, tools and equipment shall be at the Contractor's expense.

In the event that it proves unduly difficult to core-drill any hole to size NX (2 1/8" approximate diameter of core), the Contractor may be permitted to reduce to size BX (1 5/8" approximate diameter of core) for any such holes with the Engineer's permission.

Measurement for payment of core drilling will be of the lineal feet of size NX hole core-drilled in rock. Payment for size NX and size BX shall be at the unit price per lineal foot for vertical drilling or at the unit price per lineal foot for angle drilling for size NX set forth in the Schedule of Prices.

3.15 DRILLER'S LOG - The Contractor shall maintain a drilling log in a form satisfactory to the Engineer and shall record therein not only lengths of holes drilled and core recovered, but also all significant changes of drilling conditions including, but not limited to, changes in rate of drill penetration, loss of drill water, and water inflow.

3.16 CORE RECOVERY AND STORAGE - Recovery of core is of prime importance in carrying out the work. The Contractor shall take all precautions to insure that the lineal feet of core recovered is a maximum and that the core is not damaged by drilling or pulling operations. The core barrel shall be pulled whenever necessary to prevent loss of, or injury to the core. The Engineer may require the use of a shorter core barrel in order to improve core recovery.

Core shall be carefully handled and stored in approved wooden core boxes which shall be furnished by the Contractor as shown on the attached detail drawing. Core intervals shall be accurately and clearly marked by the Contractor on the core at the end of each core run and on wooden separators between the core runs. All gaps in core recovery and locations where samples are taken shall be filled by wooden spacers with the length of missing core marked thereon.

The Engineer will select and remove samples for laboratory study and testing. Samples of softer materials will be wrapped on site to preserve their natural water content, and the Contractor shall have suitable wrapping materials available. This work will normally be performed by the Engineer, but some of the work may be delegated to the Contractor.

Payment for core recovery, temporary storage, and delivery to permanent storage will be made a part of the unit price for core drilling as set forth in the Schedule of Prices.

3.17 SAMPLES AND RECORDS - Each sample shall be labelled to show plainly the number of the boring, the sample number, description, depth

below the surface from which the size came, and the resistance to penetration of the sampler.

During the progress of each boring, Contractor shall keep a continuous and accurate log of the materials encountered and a complete record of the operation of sinking the boring. Where driving is permitted on the sampler he shall also keep a record of the number of blows required to advance the sampling barrel each 6" in the soil where each sample is taken.

Records shall include at least the following data:

Dates and times of beginning and completion of work.

Identifying number and location of test boring.

Ground surface elevation at the boring.

Diameter and description of casing.

Total length of each size of casing.

Length of casing extending below ground surface at the completion of the boring.

Weight, number of blows, and drop of hammer used to drive the casing each successive foot.

Depth of ground water table.

Depth of top of each different material penetrated.

Depth of the bottom of sampler at start of driving for each sample.

Depth to which the sampler was driven.

Weight and drop of hammer used to drive the sampler and number of blows required to drive it each 6" for each sample.

Methods and forces used to push sampler tube when not driven.

Length of sample obtained.

Distance from the bottom of the sampler to the lower end of the sample when the sampler is not filled to the bottom, and any other circumstances of obtaining the sample.

Stratum represented by the sample.

Loss or gain of drilling water or mud.

Any sudden dropping of drill rods or other abnormal behavior.

Type and size designation of core drill used.

Lengths of each core run and length and percentage of core recovered from each run.

Time required to drill each consecutive run.

Depth to top of each core run.

Soil shall be described in accordance with the following classifications:

(1) Texture and Composition: Topsoil, fill including complete description of each character and constituents, gravel, sand, silt, clay, organic silt, peat, meadow mat, etc. Designate predominant soil type last, as in: sandy, silty clay with little gravel, or fibrous organic silt, some sand lenses and evidences of leaves and grass roots.

(2) Consistency: Sands and gravels - loose, medium, compact, very compact. Clays and silts - soft, medium, stiff, hard.

(3) Plasticity: Non-plastic, slightly plastic, plastic, fat, sticky, etc.

(4) Color: Light, dark, black, blue, yellow, red, brown, etc., as in: dark greenish brown organic silt with some sand.

(5) Moisture: Dry, moist, wet, etc.

Rock core shall be described in accordance with the following criteria:

(1) Driller's description and identification of rock: Rock type, color.

(2) Texture and condition: Soundness, weathering, jointing, special features.

At completion of the work, copies in ozalid print form of logs and records of the borings, records of the ground water level observations, and the plan showing the actual locations and surface elevations of

all borings required shall be delivered in quadruplicate to the Engineer along with one copy in reproducible form (transparency).

The purpose of these borings is to provide reliable information regarding the character and elevation of the several soil formations. Contractor shall give Engineer every facility for obtaining his own records and determining every detail of the work as it progresses.

3.18 REAMING AND CASING - If prevailing rock conditions require, the Contractor shall ream and case holes as necessary in order to maintain the hole and to obtain satisfactory core recovery. The casing shall be large enough to allow core drilling below the bottom of the casing.

Measurement for payment for reaming and casing shall be included in the price of Core Drilling as set forth in the Schedule of Prices.

In the event that casing cannot be retrieved from the hole or is left in the hole at the Engineer's instruction, the Contractor shall receive payment for the footage of casing remaining in the hole at the end of drilling operations at the unit price set forth in the Schedule of Prices.

3.19 CEMENTING - If required by rock conditions at any point in a drill hole, the Contractor shall cement drill holes at such locations in order to continue drilling operations.

Measurement for payment for cementing drill holes shall be included in the cost of Core Drilling as set forth in the Schedule of Prices.

3.20 WATER TESTING - Rock sections in drill holes shall be water tested at intervals designated by the Engineer, utilizing the packer method as the hole is advanced. Tests will be run at varying pressures as directed by the Engineer, with a maximum test pressure of 100 psi. Prior to each test, the hole shall be thoroughly cleaned by flushing with water to remove all drilling sludge. The test section shall then be sealed by an approved hydraulic or mechanical packer and the test shall be conducted by pumping clean water, free of suspended solids, into the test section through standard drill rods. If the packer does not develop an adequate seal against the walls of the hole, the Engineer may direct that the packer be set at another level in the hole.

For each test section, as many as five tests at various pressures for equal periods of 5 minutes may be used. In general, two intervals shall be tested in each hole but additional test sections may be required by the Engineer.

The pump used shall be capable of pumping 50 gpm at a steady rate. The pressure gauge shall be a precision instrument of durable construction graduated to read increments of 1 psi. The water meter shall be capable of accurately recording volumes to the nearest gallon.

Measurement for payment for water testing shall be on a per test basis. Payment will be at the unit price per test set forth in the Schedule of Prices.

<u>3.21</u> <u>MOVES BETWEEN HOLES</u> - The Contractor shall be responsible for all work involved in making moves between drill holes, including construction of access to and preparing the drill hole sites for drilling, and shall provide all necessary equipment therefor. In those cases where the Engineer determines that the site preparation was unusually difficult involving for instance dozer excavation or unusual restoration work such as extensive grading, the Contractor shall perform the work under a Change Order for extra work as provided in the General Specifications.

Measurement for payment for moves between holes shall be made part of Mobilization and Demobilization as set forth in the Schedule of Prices.

<u>3.22</u> <u>STANDBY TIME</u> - The Contractor shall make allowance in his Schedule of Prices for all anticipated delays in the conduct of his Work including time spent fishing for tools lost in the hole but excepting work stoppages ordered by the Engineer. If the Contractor is prepared and able to proceed with drilling and testing work but is requested by the Engineer to cease and stand by, standby time shall be paid at the rate of $45.00 per hour for every hour lost by the Contractor due to this cause during normal working time.

<u>3.23</u> <u>OBSERVATION HOLES</u> - The Engineer may designate some or all of the holes as observation holes for later ground water measurements. All observation holes shall have a casing which is sealed to the rock as directed by the Engineer. The Contractor shall thread the top of the casing and provide a suitable threaded cap and lock.

The Engineer may require the Contractor to install 1-1/2 inch PVC tubing in some or all of the observation holes. The Contractor shall maintain a supply of at least 200 lineal feet of tubing for this purpose. The unused tubing will remain the property of the Contractor. The length of tubing installed, the location and amount of slotting, and other installation details shall be determined by the Engineer.

Payment for providing and installing PVC tubing shall be made at the unit prices per lineal foot installed as set forth in the Schedule of Prices. The cost of capping observation holes shall be incidental to drilling and core drilling and no separate payment shall be made for capping.

3.24 OTHER HOLES - Holes, which are not designated as observation holes, shall be backfilled with cement grout in accordance with the Engineer's instructions. Cement grout backfilling of holes shall be included in the cost of Core Drilling as set forth in the Schedule of Prices.

3.25 HOLE COMPLETION

(A) The Contractor shall complete all test holes in such a manner as to insure against settlement or slippage of backfill which could result in a condition hazardous to persons or property. At the Engineer's instruction, some or all of the holes may be preserved for water level observations in accordance with article 3.23.

(B) Completed holes shall be immediately backfilled to within 18 inches of ground surface with cement grout having cement-sand ratio of 1:2. Cement shall conform to ASTM C 150, Type V or II. Sand shall be of the following gradation:

Sieve Size U.S. Standard Series	Percentage Passing Sieves
16	100
30	60 - 85
50	20 - 50
100	10 - 30
200	0 - 5

(C) Payment for backfilling shall be included in the cost of drilling in soil or core drilling.

APPENDIX B

SAMPLE GAS DETECTION AND CONTROL SPECIFICATION

Included in General or Special Conditions:

5:01 Scope of Work

1. The Contractor shall conduct all Work in conformance with applicable Federal, State, and local regulations. This Specification includes items which may require more testing for flammable gas and the maintenance of lower concentrations of flammable gas than called for in the foregoing.

Included in Detailed Specifications:

5:05 Gas Detection and Control

5:05.1 Scope of Work:

1. This Item defines the minimum precautions and requirements with regard to the detection and control of hazardous gases which shall apply to all underground Work under this Contract.

2. For the Contractor's information, portions of this Item were obtained from the California Division of Industrial Safety, Tunnel Safety Orders (Register 73, No. 34-8-25-73).

5:05.2 Geologic Conditions:

This is a Potentially Gassy tunnel. The Contractor shall become cognizant of the geologic conditions having the potential for producing hazardous gases. The Contractor's attention is directed to the attached Sections of the (provide source citation). The following sections contain information pertinent to the gaseous conditions which may be anticipated but is not intended to describe exact conditions to be encountered:

(Included here are specific references to investigations which define the potential gassy conditions, such as references to nearby gas wells, specific data respecting measurements of gas taken during drill hole exploration, preliminary geological report, and summaries of previous experience in nearby tunnel construction.)

5:05.3 Submittals:

At least 15 days prior to the commencement of excavation in rock, the Contractor shall prepare and submit to the Engineer for review a plan for the detection and control of potentially hazardous gases.

5:05.4 Construction Requirements:

1. Permissible Equipment:

   All equipment used within 300 feet of a working face shall be certified permissible by the Mine Enforcement and Safety Administration (MESA), formerly U. S. Bureau of Mines.

2. Exploratory drilling:

   The Contractor shall maintain no less than one feeler hole at least 20 feet forward of the working face, as specified in item 5:03.12. Measurements for Flammable gases shall be taken continuously as near as practical to the hole during the drilling process. If pockets of Flammable gas are encountered, drilling shall be stopped and the gas allowed to dissipate. Drilling will not be permitted if the concentration of Flammable gas exceeds 20% of LEL measured not less than 12 inches from the roof, floor, walls, or face of the workings. The Contractor may increase the ventilation or add supplementary ventilation to assist in dilution and dissipation of gas.

3. Tests for Flammable gases:

   a. Tests for all Flammable gases shall be made by qualified persons as determined and verified by the Engineer. The Contractor shall maintain a record of such qualifications. Instruments used for tests and monitoring for Flammable gases shall be certified as complying with appropriate Mine Enforcement and Safety Administration certification for such measurements.

   b. Tests shall be made throughout all underground openings in accordance with sub-item e below as a minimum, whether or not such openings are being worked.

c. When excavating by conventional drill and blast methods, the air shall be tested prior to re-entry after blasting, and continuously when men are working underground.

d. Automatic and manual gas monitoring equipment shall be provided for the heading and return air when mechanical excavators are used. The monitor shall signal the heading and shut down electric power in the excavation, except for ventilation and emergency illumination equipment, when 20 percent or more of LEL is encountered. In addition, a manual shut down control shall be provided near the heading.

e. At other times, tests shall be made prior to the start of each work shift and at least every four work hours.

f. Tests for Flammable gas shall be conducted in the return air and not less than 12 inches from the roof, face, floor and walls in any open workings.

g. Tests for Flammable petroleum vapors shall be conducted in the return air and not less than three inches from the roof, face, floor, and walls in any open workings.

h. If more than 10 percent of the LEL of Flammable gas or petroleum vapor is found in the tunnel, any Work therein shall be conducted with extreme care and steps shall be taken to improve ventilation. The tests shall then be made continuously during the working shift and underground workers shall be informed of the readings.

4. Tests for Air Quality:

Tests shall be made for air quality in accordance with 20CFR1926, Sub-part S, paragraph 1926.800 (c) (1).

5. Construction Operations:

a. Whenever any of the following conditions have been encountered, all underground Work shall cease, employees shall be removed, and re-entry shall be prohibited except for rescue purposes or Work necessary to reduce concentration of flammable gases to less than 20% LEL or to increase oxygen content to 20%.

(1) An underground ignition of gas or vapor occurs.

(2) 20 percent of LEL of Flammable gas or vapor is encountered.

(3) A poisonous or suffocating gas in concentrations dangerous to life is encountered.

(4) Less than 20 percent oxygen in the atmosphere is encountered.

b. Welding, cutting, or other spark producing operations shall only be done in atmospheres containing less than 10 percent LEL and under the direct supervision of qualified persons. Tests for gas and vapors shall be made before such operations start and continuously during such operation.

6. Ventilation:

a. Ventilation systems shall exhaust Flammable gas or vapors from the tunnel, shall be provided with explosion relief mechanisms, and shall be constructed of fireproof materials. Ventilation systems shall be capable of actuation from the surface.

b. Fresh air shall be delivered in adequate quantities to all underground Work areas. The supply shall be at least sufficient to prevent dangerous or harmful accumulations of dusts, fumes, vapors or gases. The lineal velocity of the air flow in the tunnel bore shall be not less than 60 feet per minute in those tunnels where blasting or rock drilling is conducted or where there are other conditions that are likely to produce dusts, fumes, vapors, and gases in harmful quantities.

c. The main ventilation system shall be so arranged that the air flow can be reversed from the surface.

d. Where Flammable gas or air contaminants have been encountered, adequate ventilation shall be maintained to keep the gas or vapor concentrations within safe limits as provided by this Item.

e. Bulkheads and forced ventilation in one direction shall be provided after holing through to prevent harmful accumulations of dusts, fumes, vapors, gases, and concrete curing compounds from exceeding allowable concentrations.

f. Auxiliary ventilation shall be provided to prevent dead air space between the face and the end of the vent line.

g. Ventilation shall be maintained to the extremity or face of all underground openings, whether worked or not, as required to dilute all Flammable gases to less than 10 percent of LEL.

7. Holing through:

Prior to holing through between any adjacent excavations, the Contractor shall take special precautions to ensure that the concentration of Flammable gas in both excavations is less than 5 percent of LEL. Immediately upon holing through, the Contractor shall establish and maintain a ventilation system for the combined excavation.

8. Smoking:

Smoking shall be prohibited underground and the Contractor shall be responsible for collecting all personal sources of ignition such as matches and lighters from all persons entering the excavation.

APPENDIX C

REPORT OF INVENTIONS

The findings of the project, as reported in this document, are primarily management controls to be applied in tunnel construction. Application of these controls are expected to make a positive contribution to improved safety and environmental impact in tunnel construction. There were no patentable inventions or discoveries resulting from this work.

125 copies

U. S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE, CAMBRIDGE, MA. 02142